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THE ROLE OF SCIENCE, TECHNOLOGY AND INNOVATION IN BUILDING RESILIENT COMMUNITIES, INCLUDING THROUGH THE CONTRIBUTION OF CITIZEN SCIENCE

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UNITED NATIONS
Geneva, 2019

United Nations publication issued by the United Nations Conference on Trade and Development.

UNCTAD/DTL/STICT/2019/11

eISBN: 978-92-1-004475-2

ACKNOWLEDGEMENTS

This study was prepared by UNCTAD staff members Clovis Freire and Daisuke Maruichi. The authors worked under the supervision of Dong Wu, Chief, Science Technology and Innovation Policy Section, and with the overall guidance of Shamika N. Sirimanne, Director, Division on Technology and Logistics.

The report benefited from major substantive contributions by Jonathan D. Paul and Wouter Buytaert, Department of Civil and Environmental Engineering, Imperial College London, principal consultants for the study.

UNCTAD appreciates the valuable inputs provided by the Governments of Austria, Brazil, Canada, Chile, the Dominican Republic, Egypt, Germany, the Islamic Republic of Iran, Japan, Kenya, Peru, South Africa, Turkey, Uganda and the United States of America, as well as from the Economic and Social Commission for Western Asia, the United Nations Office for Disaster Risk Reduction, the World Health Organization and the World Meteorological Organization.

The publication benefited significantly from discussions and inputs during the intersessional panel of the United Nations Commission on Science and Technology for Development (January 2019) and the twenty-second session of the Commission (May 2019).

Magali Studer designed the cover. Malou Pasinos provided administrative support.

NOTE

UNCTAD serves as the lead entity within the United Nations Secretariat for matters related to science and technology as part of its work on the integrated treatment of trade and development, investment and finance. The current UNCTAD work programme is based on the mandates set at quadrennial conferences, as well as on the decisions of the General Assembly of the United Nations and the United Nations Economic and Social Council that draw upon the recommendations of the United Nations Commission on Science and Technology for Development, which is served by the UNCTAD secretariat. The UNCTAD work programme is built on its three pillars of research analysis, consensus-building and technical cooperation, and is carried out through intergovernmental deliberations, research and analysis, technical assistance activities, seminars, workshops and conferences.

This series of publications seeks to contribute to exploring current issues in science, technology and innovation, with particular emphasis on their impact on developing countries.

Main text

The terms “country” and “economy”, as appropriate, also refer to territories or areas. The designations of country groups are intended solely for statistical or analytical convenience and do not necessarily express a judgment about the stage of development reached by a particular country or area.

The term “dollars” ($) refers to United States dollars unless otherwise specified.

Tables

Two dots (..) indicate that the data are not available or are not separately reported.

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A. INTRODUCTION

People around the world are continuously affected by shocks from different sources, including economic crises, health emergencies, social conflicts, war and natural disasters. For example, in 2017, natural disasters killed over 11,000 people and affected more than 95 million (table 1). In the economic dimension, two recent broad-based shocks – the European sovereign debt crisis in 2010–2012 and the global commodity price realignments in 2014–2016 – have resulted in an economic slowdown, affecting jobs and the capacity of Governments to provide better access to public services. These shocks have a significant impact on the progress of communities and countries towards sustainable development. Moreover, global economic interdependence has created increasingly complex and unpredictable threats. Disasters caused by natural hazards lead to supply chain disruptions, often resulting in widespread damage and systemic losses. Another complex threat is the risk of natural hazards triggering technological disasters, such as the Fukushima Daiichi nuclear disaster initiated primarily by the tsunami following the Tōhoku earthquake in March 2011. Such shocks can derail and even set back progress towards sustainable development.

Building the resilience of people, communities and countries is therefore critical for the achievement of the 2030 Agenda for Sustainable Development and the Sustainable Development Goals (**box 1**). A resilient community is one that is organized socially in a way that sufficiently empowers its members to be better able to absorb and adapt to shocks. Such a community must have a diversified economy that can adapt to changes in circumstances, self-organize to continue functioning in times of crisis and carry out its activities without harming the environment. Science, technology and innovation (STI) have a critical role to play in each of these dimensions. First, technologies, particularly digital technologies, have played a vital role in empowering and giving voice to people, including the most vulnerable. They are used for extending access to education and health, for assessing and monitoring health and environmental risks, for connecting people within and outside communities and for the operationalization of early warning systems. Second, innovation is a key driver of diversification and economic development, which increases the ability of economies to adapt to shocks and thrive. Innovative solutions in infrastructure are key in protecting them from failure and avoiding a negative impact on communities. Third, new technologies and innovative products and services hold the promise of decoupling economic development from environmental degradation, promoting environmental sustainability.

Table 1 Global impact of hazards, selected indicators

Type of hazard	Impact	2017	Annual average (2008–2017)
Air pollution-related disease	Death	7 000 000[c]	..
Non-communicable disease		41 000 000[c]	..
Road traffic accident		1 250 000[d]	..
War and conflict		180 000[c]	..
Natural disaster[a]		11 843	72 390
Industrial accident[b]		4 615	6 802
Natural disaster	Affected (injured, homeless or requiring assistance)	95 900 000	199 100 000
Industrial accident		21 497	65 894
Natural disaster	Displaced (number of people)	18 800 000	24 600 000
Conflict		11 800 000	7 000 000
Natural disaster	Economic costs (millions of United States dollars)	337 500	152 800[e]
Industrial accident		5	8 000[e]

Source: UNCTAD calculations, based on data from the emergency events database of Université Catholique de Louvain; Internal Displacement Monitoring Centre, 2018; and World Health Organization, 2018.

Notes:

[a] "Natural disaster" includes earthquake, mass movement, volcanic activity, extreme temperature, fog, storm, flood, landslide, wave action, drought, glacial lake outburst, wildfire, epidemic, insect infestation, animal accident and impact of asteroids, meteoroids and comets.

[b] "Industrial accident" includes chemical spill, collapse, explosion, fire, gas leak, poisoning, radiation, oil spill and transport accidents such as air, road, rail, water and miscellaneous accidents (collapse, explosion, fire and other).

[c] Estimates for 2016.

[d] Estimates for 2013.

[e] Average cost of damage from 2007 to 2016 in 2016 prices.

Box 1 Resilience, risk reduction and sustainable development

This study adopts the United Nations harmonized definition of resilience as approved by the High-level Committee on Programmes of the United Nations System Chief Executives Board for Coordination, as part of an analytical framework for the United Nations system to better understand the relationship between the risk of threats and resilience in the context of sustainable development.

Resilience is "the ability of individuals, households, communities, cities, institutions, systems and societies to prevent, resist, absorb, adapt, respond and recover positively, efficiently and effectively when faced with a wide range of risks, while maintaining an acceptable level of functioning and without compromising long-term prospects for sustainable development, peace and security, human rights and well-being for all".

The framework is based on systems thinking to identify and understand the complex interlinkages among risks and other sustainable development issues at multiple levels; the risk and resilience equation (risk = 1/resilience) to identify different efforts and expertise to reduce risk and increase resilience in a given context; and a prevention lens to ensure a proactive approach. The framework recognizes that it is critical both to make progress to achieve the Sustainable Development Goals and to address potential threats that can set back that progress. At the same time, the primary focus of the framework is on the threats that might set back such progress.

Sources: CEB, 2017.

This study identifies, analyses and presents key issues concerning the role of STI in building resilient communities. It is structured as follows. Section B discusses the role of science in community resilience, focusing on the use of traditional, local and indigenous knowledge and on new approaches to engaging the participation of citizens in science for building resilience. Section C illustrates new technological solutions for building resilient communities, their characteristics and skills requirements. Section D discusses mission-driven innovation systems for building resilient communities and new approaches to innovation that are enabled by digital technologies. Section E discusses some key technical, social, market-related and policy challenges in using STI for building resilient communities. Section F presents some considerations regarding STI policies. Section G discusses international collaboration for the provision of global and national solutions on STI for resilience. Section H concludes by presenting policy considerations for policymakers and other relevant stakeholders.

B. SCIENCE: UNDERSTANDING RESILIENT COMMUNITIES AND ENGAGING PARTICIPATION

Diverse fields of scientific knowledge contribute directly and indirectly to building resilient communities, from scientific discoveries in biology and medicine that uncover new mechanisms of the transmission of diseases, to advances in weather prediction models that increase the reliability of early warning systems. This study focuses on three aspects of the role of science in building resilient communities: the status of the scientific research that seeks to better understand the resilience of communities; the use of traditional, local and indigenous knowledge; and recent ways to engage citizens in contributing to and participating in scientific research on resilience.

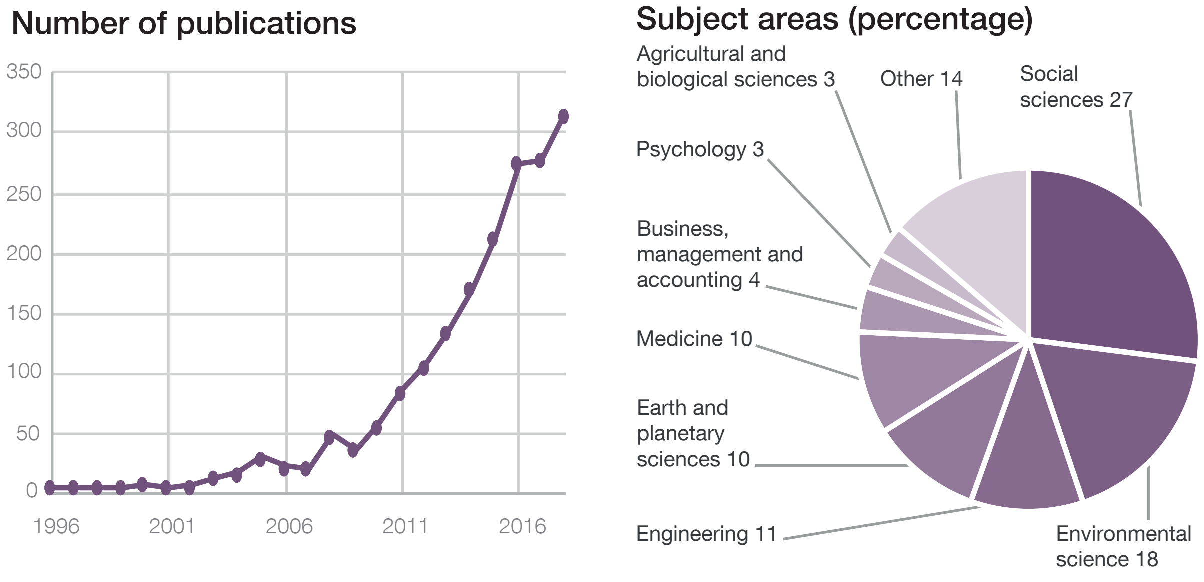
1. THE SCIENCE OF RESILIENT COMMUNITIES

STI policies can allocate resources to conduct science in priority areas that contribute to building resilient communities. Science focused exclusively on community resilience has been productive. Worldwide, it led to over 1,700 publications in the English language in the period 1996–2018, representing 32 per cent of the publications in the same period related to resilience to disasters and twice as many as the number of publications focused on community-based disaster risk reduction. Scientific interest in the topic has increased, as seen by the growth in the number of publications per year, from single digits in the early 2000s to over 300 publications in 2018. Reflecting the multidimensional nature of resilience, the areas of knowledge engaged in most of this research are the social sciences, environmental science, engineering, earth and planetary sciences and medicine (figure 1).

An analysis of the topics covered in the abstracts of these publications provides information about the areas of scientific knowledge that could be prioritized by Governments to promote community resilience. There are five main clusters of research centred around disaster risk reduction, climate change, infrastructure, livelihoods and health. These clusters share many common topics, particularly related to climate change and disaster risk reduction.

Research on communities resilient to the effects of climate change deals with ecosystems, natural hazards, sea level rise, coastal zone communities and

Figure 1 Scientific publications related to community resilience, 1996–2018



Source: UNCTAD calculations, based on data from the Scopus database.

adaptive management. For example, such research identifies the optimum combination of adaptation and mitigation measures in fast-growing cities (Roy, 2009). It studies coastal protection provided by infrastructure, natural ecosystems and the innovative opportunities to combine the two into hybrid approaches for coastal protection (Sutton-Grier *et al.*, 2015). It also assesses impacts and adaptation strategies for climate change in rural communities in different ecological zones (Dumenu and Obeng, 2016). Natural hazards, particularly earthquakes and hurricanes, are also a key topic in research that focuses on infrastructure for resilience. Research focused on livelihoods covers both rural and urban issues and deals with economic diversification and social capital. Health-related research tends to focus on psychological resilience, education and prevention and the different impacts on men and women and children and adults.

Scientific policies in support of community resilience should also consider the role of international cooperation. A large share of the relevant research has been produced by researchers (singly or as co-authors) in several countries, mostly in the United States (45 per cent), followed by researchers in Australia (17 per cent), the United Kingdom of Great Britain and Northern Ireland (9 per cent), Canada (5 per cent) and New Zealand (5 per cent). An analysis of co-authorship shows that most collaborations have been among researchers in Australia, the United Kingdom and the United States. The majority of the research is conducted in universities, and some have contributed a considerable number of publications, such as the University of Queensland, Australia (28); Massey University, New Zealand (26); Politecnico di Torino, Italy (24); the University of California, United States (24); and Kyoto University, Japan (23).

Countries with higher levels of scientific production related to resilient communities have funded scientific research in priority areas that are relevant to these studies. For example, the Australian Research Council, one of the Government's main agencies for allocating research funding to researchers at Australian universities, has identified environmental change as one of the nine science and research priorities (Australian Research Council, 2018). A large share of the research related to community resilience produced in the country covers the impact of environmental change in terms of natural hazards (e.g. bushfires, floods and droughts). Some countries have separate research councils or funding agencies for the social sciences, engineering and environmental science. This approach may increase opportunities for funding research on community resilience based on these different vantage points, but obtaining funds for more holistic research that seeks to focus on multidimensional sustainable transformation and its impact on resilience could also become a challenge.

2. HARNESSING TRADITIONAL, LOCAL AND INDIGENOUS KNOWLEDGE

Harnessing traditional, local and indigenous knowledge could lead to new scientific developments that contribute to building resilient communities (**box 2**).[1] Indigenous knowledge is usually acquired through interaction with the land and to ensure survival. Therefore, this knowledge is well suited to informing science that contributes to increasing the resilience of communities in the face of well-known natural hazards (e.g. floods and droughts) and with regard to their livelihoods (e.g. agriculture, animal husbandry and wildlife management). Harnessing traditional knowledge also contributes to sustaining communities' traditional values and in strengthening their identity, while also promoting the engagement of women and vulnerable groups, which are important elements in building resilience (Islam *et al.*, 2017; Laurence *et al.*, 2009). Scaling up, adapting and making this knowledge accessible often requires support from Governments and the international community. A practical way is through online databases of traditional knowledge such as the traditional Chinese medicine patents database, the traditional knowledge digital library in India, the traditional knowledge portal in the Republic of Korea and the Genesys gateway to generic resources.[2] In some countries, scientific funding bodies have incentivized the use of indigenous knowledge in science. For example, in South Africa, indigenous knowledge systems have been a cross-cutting theme of the 10-Year Innovation Plan of the National Research Foundation, including with a focus on climate change.[3] In Canada, Polar Knowledge Canada, a federal agency responsible for advancing Canada's knowledge of the Arctic, is providing $8.1 million in 2017–2019 to fund projects that leverage indigenous knowledge to promote sustainability and resilience to the impact of changing ice conditions.

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[1] See, for example, Hiwasaki et al., 2014.

[2] See Liu and Sun, 2004; www.tkdl.res.in/tkdl/langdefault/common/Home.asp?GL=Eng; www.koreantk.com/; and https://www.genesys-pgr.org/.

[3] See https://www.nrf.ac.za/division/funding/indigenous-knowledge-systems-iks-2019.

Box 2 Uganda: Harnessing traditional knowledge to control vector-borne diseases

The indigenous knowledge that Phytolacca dodecandra, a locally abundant wild plant, had successfully been used to control human and animal disease, has resulted in the development of a potent commercial insecticide to control vector-borne diseases. The project started in the 1990s, to promote the production of this plant as a natural biodegradable and environmentally safe product to control freshwater snails and other vectors such as mosquitoes. It was inspired by earlier work at Addis Ababa University to control schistosomiasis or bilharzia in Ethiopian communities. The project tested the plant for its effectiveness and subsequently developed an insecticide used for the containment of snails that cause bilharzia in humans and liver flukes in livestock.

Source: Based on a contribution from the Government of Uganda.

3. CITIZEN SCIENCE FOR BUILDING RESILIENT COMMUNITIES

Citizen science refers to the involvement of non-scientist citizens in the generation of new scientific knowledge. This approach combines the Internet, smartphones and social media with low-cost sensor networks to provide extensive and real-time information for community resilience in developing countries, as well as to improve data provision in data-scarce regions.[4] Citizen science can also serve to educate and empower communities and stakeholders that might otherwise be bypassed by more traditional processes of knowledge generation. Such an approach has been adopted in risk management for some time; bottom-up, community-led projects that would nowadays be classified as citizen science were recognized as hugely beneficial to capacity-building as early as the 1980s.[5] This approach is not restricted to disaster risk reduction. For example, other projects include the Zika education and prevention mapping project of the National Aeronautics and Space Administration, aimed at enlisting thousands of students to collect data on mosquitoes to improve the tracking and control of the Zika virus; the Global Mosquito Alert Consortium, aimed at leveraging networks of scientists and volunteers for the global surveillance and control of mosquito species known to carry certain diseases (e.g. the Zika virus, yellow fever, chikungunya fever, dengue fever, malaria and the west Nile virus); and Earth Challenge 2020, which seeks to engage millions of people and aggregate and collect more than 1 billion data points on air and water quality, biodiversity and human health (**box 3**).[6]

Box 3 Examples of citizen science projects

The Agroclimate Impact Reporter is an online citizen science application designed for the collection and reporting of weather and climate impacts on farm operations across Canada. It produces a live impact map and monthly maps using data collected through its citizen science network. These maps enable producers, scientists and decision makers to better understand the local and regional effects of agricultural and climate conditions and identify emerging risks to the broader agriculture sector.

Cyber Tracker leverages the expertise of Indigenous residents in Kalahari to understand the impact of infectious diseases on populations of wildlife such as gorillas, chimpanzees and antelopes. Trackers can select images and transmit sightings using global positioning system (GPS) data. This programme helps scientists track the patterns of such animals and, in turn, give a voice to the Indigenous residents and their unique knowledge.

Ice Watch volunteers contribute to scientific understanding of climate change by helping to record and analyse when ice forms and thaws on bodies of water. They provide critical data to cover gaps in the current monitoring network. The programme allows people of all ages to participate in discovering how and why the environment is changing. It is part of the Nature Watch suite of Canada's national volunteer monitoring programmes, designed to help identify ecological changes that may be affecting the environment.

The National Map Corps is an online crowdsourced mapping project of the United States Geological Survey that allows volunteers to verify data, keep data current or revise data in the event of emergencies. It contributes to the National Map, a collaborative effort with federal, state and local partners to improve topographic information. The National Map includes, on a single platform, data on boundaries, elevation, geographic names, hydrography, land cover, structures and transportation from a variety of sources.

The SISS-Geo system of the Oswaldo Cruz Foundation, Brazil, involves the use of mobile telephones by users to transmit georeferenced records, to generate alert models of occurrences of diseases in the wild, particularly those with the potential of human involvement, and prediction models of ecological risks of disease emergence. The system provides a fast and efficient flow of information between government sectors and society through citizen science and is integrated with georeferenced government platforms.

The Urban Heat Island Mapping Campaign aids cities in preparing for extreme heat events by enabling them to respond in an informed and targeted manner. An objective is to generate detailed maps showing heat islands and to inform authorities and residents when they should act to avert harm to people, property or infrastructure. It also improves understanding of how much and how fast urban heat islands heat and cool throughout the day and as a function of different land cover types.

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[4] See, for example, Mueller et al., 2012.

[5] See, for example, Paul et al., 2018.

[6] See Tyson et al., 2018.

Youth Mappers is a local-level field-mapping project of the United States Agency for International Development to support development by leveraging a global network of universities to create and use open geographic data and by empowering youth to become leaders in building resilient societies and defining the world in which they live. The network consists of 143 universities in 42 countries supporting projects related to disaster response, recovery and preparedness, health, agriculture, the environment, resource management and others.

Source: Based on contributions from the Governments of Brazil, Canada and the United States.

a. *Types of citizen science*

Citizen science may involve data collection, interpretation, analysis and the dissemination of results (figure 2). It differs from more general stakeholder engagement by the active involvement of citizen volunteers throughout the life cycle of a project, necessitating motivational aspects, such as improved living standards, the provision of and quality local education and fostering of a sense of national pride (Buytaert *et al.*, 2014). Historically, citizen science has often been often applied to environmental data collection by volunteers.[7] Given that most community-based responses to hazards take a preventative approach or are based on real-time observation and mitigation,[8] in many projects, the role of local stakeholders is strictly limited to information gathering. Such citizen sensors are less involved in the aims and formulation of a project but can still provide good quality data in data-scarce regions (Robson, 2012; **box 4**).

Figure 2 Levels of participation in citizen science

4	Extreme	• Collaborative science; problem definition, data collection, analysis	Long-term regional resilience building planning; many varied stakeholders
3	Participatory science	• Participation in problem definition and data collection	Work with local farmers to develop smart irrigation practices
2	Distributed intelligence	• Citizens as basic interpreters	Floodwater estimation using telephone cameras and applications
1	Crowdsourcing	• Citizens as sensors	Basic measurement of river level, ground shaking, land-use change

Source: UNCTAD, based on Haklay, 2012.

Box 4 Kenya: A crowdsourced approach to hydrological monitoring

The project "A crowdsourced approach for hydrological monitoring in Sondu Miriu river basin located in western Kenya" has evaluated the quality and quantity of the data generated by citizens in a remote basin. It has also assessed whether crowdsourcing is a suitable method to overcome data scarcity. The methodology involved the installation of water gauges equipped with signboards explaining the monitoring process to passersby. Results were sent via a text message-based data collection framework that included immediate feedback to citizens.

The results showed that, within the first year, 124 citizens reported 1,175 valid measurements. However, 13 citizens were active observers, providing more than 10 measurements. The comparison of crowdsourced data with data from automatic gauging stations revealed a high quality of data. The driving factors that kept participants involved included feedback to prevent raising unrealistic expectations associated with monitoring, management plans and rewards, using available simple mobile telephone technology and reimbursing costs.

Source: Based on a contribution from the Government of Kenya.

The recent tendency is to involve volunteers in all intellectual aspects of science, rather than to capitalize on them as a low-cost workforce.[9] From this perspective, it is citizens who define the problem at hand, then collect relevant information (e.g. observations of stream flow, air quality, ground shaking and flood damage). This extreme citizen science, or collaborative learning, typically involves spending extended periods understanding the needs and concerns of a range of local stakeholders (Haklay, 2012; **box 5**).

Box 5 Canada: Examples of citizen science participation types

Citizen science projects in Canada exist along a spectrum.

The first type is one-way, tapping into already active networks of people and obtaining data through websites and applications. For example, Bumble Bee Watch at the University of Ottawa encourages people to take pictures of bees and upload the data onto their platforms for scientists to use in their analytical research. In return, citizens learn about the different types of bees and what they can do to increase the number of bees foraging in their communities.

The second type is citizen-facilitated science, whereby the public gives researchers access to their property and in turn are engaged in projects, increasing their awareness of science and scientific literacy. An example is a study at the University of Guelph of the interaction between domestic cats and wild birds by setting up field cameras in suburban homeowners' backyards.

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[7] See, for example, Huddart et al., 2016.

[8] See, for example, Johnson et al., 2017; and Rieger, 2016.

[9] See, for example, Buytaert et al., 2016.

The third type is an active team approach, or collaborative community science, whereby community members provide input to the design of a research project through local or traditional knowledge. For example, some studies on caribou populations in the Northwest Territories have been conducted in partnership with First Nations people acknowledged as co-authors on academic papers given their local and traditional knowledge inputs to the design of the research.

Source: Based on a contribution from the Government of Canada.

Community engagement and collaborative science have generated actionable results in several contexts, from rural areas in western Nepal experiencing multiple vulnerabilities, to urban areas at risk from repeated flooding, such as in Bangladesh and Mozambique (Kattelmann, 2003).[10] The most effective projects involve two-way information flows over the entire project, which improves citizen participation.[11] In many of these projects, situational analyses lead to a prior understanding of local livelihoods, power structures and institutional frameworks, which enable the scientific interventions to be better targeted, increasing local buy-in and long-term project sustainability.[12]

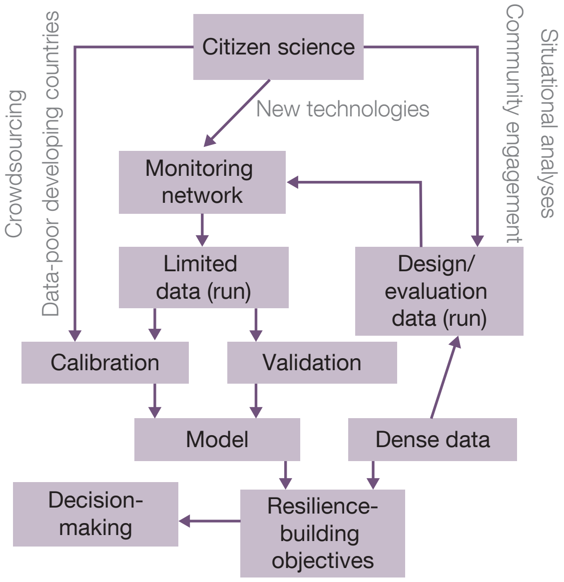
In citizen science, an effort should be made to provide information and data back to non-scientists in a comprehensible manner, which serves as an incentive for further citizen participation. For example, in hydrological research, this process could take the form of irrigation requirements (for farmers), modelled water uses and demand (for policymakers) and flood vulnerability maps (for the public). Although this important feedback aspect of citizen science has been lightly developed, particularly in a resilience-building context, Internet-based technologies create opportunities for user feedback and communications beyond a research project itself.[13] In the small number of cases where information provision and citizen feedback are integral to project development, the situational awareness and participation rates of participants, as well as levels of community buy-in, are high.[14]

b. *Use of technology in citizen science*

Many have equated the explosion of citizen science research projects (in resilience-building and beyond) with the rapid technological and scientific development in the past 10–15 years. Small, inexpensive sensors are now widely available and easy to connect to smartphones, which themselves are generally fully connected to the Internet and include sophisticated cameras as standard features. The dramatic pace of this change can be seen in many of the most impoverished communities globally, in which access to clean running water and electricity is lacking, yet the provision of mobile telephones is widespread (Baum *et al.*, 2014). These developments, together with advances in knowledge communications and data processing and analysis, are opening new pathways for citizen science to improve resilience-building efforts at a community scale (Buytaert *et al.*, 2014). New information and communications technology (ICT) has augmented the flow of knowledge and data, while the Internet of things allows for a much more interactive and dynamic approach to research design, knowledge generation and information provision at the community level.

Figure 3 shows how the operation and design of new technologies can benefit a citizen science approach, to yield enhanced decision-making capabilities in community-led resilience-building efforts.

Figure 3 Use of citizen science and new technologies to build resilience in a developmental context



Source: UNCTAD.

In this example, a monitoring network is established that leverages some facet of a new technology (e.g. measurements of river levels using a network of citizens equipped with smartphone cameras), which feeds data into a forecasting model (e.g. for floods). This model is then calibrated by the records of citizens and validated

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[10] See, for example, Lane et al., 2011.

[11] See, for example, Karpouzoglou et al., 2016.

[12] See, for example, Paul et al., 2018.

[13] See, for example, Mueller et al., 2012; and Rosser et al., 2017.

[14] See, for example, Liu et al., 2011.

Table 2 Use of new technology to build resilience in developing countries at the community level

Technology and innovations	Location(s)	Objectives	Citizen scientist engagement
Novel sensors to measure rainfall, river level, soil moisture and stream flow, coupled with bespoke modelling approaches	Lake Tana (Ethiopia), Mustang (Nepal), Andes (Peru)	Impact of changing land use and increasing population	Hydrological monitoring
New sensor networks installed at the community level	Central Nepal	Rainfall and landslide risk reduction	Rainfall monitoring and geological mapping
Citizen-led drone mapping and design	Malaysia, Hawaii (United States)	Disaster response (volcano) and impact of land-use change	Drone image submission and mapmaking
New integrated Mapster smartphone application	Myanmar, Champaign (United States; testing)	Emergency management and urban flood response	Social media and access to maps (two-way information flow)
Flood hazard mapping through Open Street Map	Nepal	Community empowerment through natural hazard planning	River level measurements, Open Street Map design and risk mapping exercises
Creek Watch smartphone application and website	Northern Mexico	Building flood resilience	Simple observations of water level and flow rates and time-stamped photographs
Integration of indigenous knowledge into numerical sea-level models	South Caribbean	Improving coastal climate resilience (sea-level change)	Semi-structured interviews and hazard mapping
New crowdsourced data sets and information management platform	Argentina, France, New Zealand	Building flood resilience	Photographs and videos for flow estimation
Citizen seismologists: Cloud-based computing tool and website for online learning	Malaysia, Viet Nam, Taiwan Province of China	Improving knowledge of and resilience to earthquakes	Damage reports and photographs, seismograph analysis, shaking reports (using smartphone accelerometers)
Remotely sensed data and volunteered geographic information	Brazil, Oxford (United Kingdom)	Flood probability mapping	Geotagged photographs from social media
Combination of wireless sensor network and citizen observatories	Sao Carlos (Brazil)	Integrated river flood risk management	Observational river monitoring
Sensors, empowerment and accountability mobile application	United Republic of Tanzania	Monitoring rural water points	Monitoring functionality status of rural water points

Sources: Buytaert et al., 2014; De Souza and Clarke, 2018; Horita et al., 2005; Johnson et al., 2017; Le Coz et al., 2016; Lemmens et al., 2017; Liang et al., 2015; Liu et al., 2011; Malakar, 2014; Rieger, 2016; Robson, 2012; Rosser et al., 2017.

against existing scientific measurements to produce an output (e.g. a prediction of flood magnitude and extent). Finally, information from the output is used both to inform policymaking and as a means of engaging with and educating local stakeholders, who may then be incentivized to suggest improvements or participate further. While it is sometimes challenging to integrate the newest forms of innovative hardware directly into resilience-building projects in the least developed countries (Paul *et al.*, 2018), promising opportunities nevertheless exist if scientific objectives are combined with a greater understanding of local livelihoods (table 2).

C. TECHNOLOGY FOR BUILDING THE RESILIENCE OF COMMUNITIES

Rapid technological development is opening new pathways for resilience-building efforts at the community level.[15] While recognizing the critical importance of traditional technologies in this context, this study focuses on market-ready new technologies to bring attention to recent developments and new opportunities. It discusses the opportunities that new technologies present, the characteristics of these technologies that make them suitable and impactful and the set of skills required to develop, implement and maintain them for community resilience.

1. BUILDING SOCIAL RESILIENCE

a. Reducing vulnerabilities and building capacities to cope

i. Health

A large share of the vulnerabilities of individuals to shocks is potentialized by the lack of or poor access to health services. In this regard, modern ICT, including space-related technologies such as satellite communications, facilitate access to health-care services through telemedicine or electronic health, allowing physicians to access, monitor and diagnose patients remotely.[16]

In the area of mental health, web-based therapy and telemedicine have applications such as in treatment for post-traumatic stress disorders; improving depression, anxiety, and stress outcomes in students; generating positive psychological interventions for cardiac patients; reducing anxiety and depression symptoms in mildly depressed adults; and treating substance abuse and eating disorders.[17] Telemedicine has also been successfully used to inform, engage and communicate with patients with chronic diseases and to empower them with ICT tools for the monitoring, training and self-management of diseases. Telemedicine can potentially improve outcomes in treatments such as cancer, chronic kidney disease and diabetes care.[18] With economic progress and increasing affluence in several middle-income countries, the burden of many of these non-communicable diseases has shifted from high to low socioeconomic groups due in part to unhealthy diets and other unhealthy behaviours.[19] Improved outcomes through telemedicine related to anxiety, depression and chronic diseases reduce the vulnerability of patients, thereby increasing resilience.

Telemedicine may be an important tool in bridging the gap in access to health services between urban and rural communities (**box 6**). Satellite technology has been used to improve care for patients in rural areas, not only in developed regions but also in developing countries in Asia and sub-Saharan Africa.[20] For spacefaring developing countries with large geographical coverage such as China and India, satellite technology is a suitable technology to reach underserved communities.[21] It allows for flexible methods of broadband communications with high reliability and cost-effective connections. It is also a tested technology with decades of use in telemedicine.[22] Satellite solutions also enable other services such as electronic learning and government; the coordination of emergency responses and humanitarian assistance; and biodiversity conservation.[23]

Box 6 Egypt: Scaling up the telemedicine solution into a national initiative to bridge the health gap in remote areas

Many forward strides have been made in recent years in the health ecosystem in Egypt, yet some challenges remained unresolved in terms of overall mortality rates, vaccination and immunization efforts and the expansion and improvement of medical infrastructure. One major challenge is the unequal distribution of resources between cities and rural governorates, as specialized medical services are located in major cities. To receive medical services, a patient must usually travel to either the capital of their governorate or to the national capital – a difficult journey for severely ill patients – and incur high transportation costs. Women are more significantly affected than men, as traditional customs may prevent them from travelling while unaccompanied. The offer of remote diagnostic services through telemedicine is a major asset to such communities. The process of successful implementation of telemedicine initiatives has influenced policy implications for the future expansion of a workable model in all marginalized regions in Egypt through the creation of strategic partnerships with major health institutions.

Source: Based on a contribution from the Government of Egypt.

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[15] See, for example, Belliveaua, 2016.

[16] See, for example, Graschew et al., 2008.

[17] See, for example, Bolier et al., 2013; Davies et al., 2014; Foa et al., 2013; Huffman et al., 2011; and Siemer et al., 2011.

[18] See, for example, Agboola et al., 2015; Diamantidis and Becker, 2014; and Baig et al., 2010.

[19] See, for example, Mayén et al., 2014.

[20] See, for example, Turnin et al., 2017; and Martín-de-Mercado et al., 2011.

[21] See, for example, Rajashekhar and Ayyangar, 2012.

[22] See, for example, Murakami et al., 1994.

[23] See, for example, Acevedo et al., 2010.

Telemedicine requires a reliable wireless communications link between clinicians and devices monitoring patients.[24] Rapid advances in wireless communications, networking technologies and medical technologies have facilitated the development of emerging mobile health-care services, including emergency health care. Developments in wireless video systems for reliable communications could significantly affect the delivery of health care, given the availability of bandwidth in the next generation of wireless communications networks and new wireless video compression standards.[25] Such technology has been used in applications such as medical video streaming and the wireless transmission of medical ultrasound videos over mobile networks.[26] Mobile telephone diffusion across all societal segments has also increased the reach of public health services to remote communities through the use of mobile telephones to exchange photographs, videos and messages between local health workers and specialized clinics (**box 7**). Mobile telephones have also been used by citizens to monitor the delivery of local government services and report failures via text messages, which amplifies the voice of ordinary citizens and improves their capacity to influence the delivery of public services directly and to hold local governments accountable.[27]

Box 7 Peru: Improving maternal and child health in rural communities along the Amazon

Through the project "River moms: Improving maternal and child health in rural communities of the Peruvian Amazon", community health agents in remote rural areas of the Amazon use smartphones to collect and send health information on pregnant women to a medical boat and health centres that attend these communities. This allows prenatal visits to be prepared and for pregnant women to receive timely attention. The project uses an application capable of collecting numerical data, text messages, GPS information, photographs, videos and audio, through enabled devices, and sending the information to an online server to which the medical boat and health centres have access. The project works with communities that have a telephone signal and the political commitment to mobilize midwives, community agents and health promoters for training.

Source: Based on a contribution from the Government of Peru.

Some challenges need to be addressed to upscale ICT solutions. For example, while the Internet may be used to build a trusted community that helps in the management of the mental health of young people, unsupervised online forums may attract adults who may take advantage of vulnerable adolescents.[28] Patients may also be unwilling to use telemedicine, despite the advantages of convenience and reduced travel, due to concerns that the remote care may be of inferior quality compared with visits to clinics and in-person care by health workers.[29] In some situations, telemedicine may not result in the expected increase in performance. For example, a study to determine whether telemedicine influenced the accuracy of triage in disaster response, in which paramedics used a mobile device to communicate with an off-site physician, showed that the procedure with the support of telemedicine took more time than conventional triage and did not result in an increase in triage accuracy (Cicero *et al.*, 2015).

In addition to ICT, other technologies also contribute to reducing vulnerability by improving health outcomes. For example, nanomedicine using traditional agents from alternative systems of medicine (e.g. nanoparticle herbs) can help treat infections through improved bioavailability and anti-inflammatory, antioxidant and immunomodulatory effects. Another example is microneedles, a new form of drug delivery with applications in many fields, including vaccine delivery, that is an improvement over conventional subcutaneous administration as it can bring simplicity and scalability to drug delivery.[30] By combining with a new class of thermostable vaccines that do not require refrigeration, this technology can improve the resilience of communities by facilitating the delivery of vaccines in challenging conditions of poor access to electricity.[31] Innovation in the development of vaccines and strategies to control disease outbreaks, such as for the treatment of Ebola virus disease, also contribute to increasing community resilience.[32]

ii. Education and knowledge

The use of computers, tablets and smartphones, and the easy production of educational videos made available through the Internet, stimulate and support the development of electronic learning and facilitate access to relevant and timely knowledge and information, improving capacity to cope with shocks. Mobile technologies can support in the process of building such capacities in innovative ways. For example, mobile telephones with video recording capabilities have been used to

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[24] See, for example, Kacimi and Pech, 2013.

[25] See, for example, Herscovici et al., 2007; and Panayides et al., 2011.

[26] See, for example, Martini et al., 2010; and Panayides et al., 2013.

[27] See, for example, Georgiadou et al., 2011.

[28] See, for example, Webb, 2008.

[29] See, for example, Call et al., 2015.

[30] See, for example, Stoeber et al., 2018; and Waghule et al., 2019.

[31] See, for example, Naik et al., 2017; and E/HLPF/2017/4.

[32] See https://www.who.int/ebola/drc-2018/faq-vaccine/en/.

engage communities in producing mini documentaries, disseminated via social media, to showcase the ways in which residents can build their capacities to increase their sense of agency. The videos present and discuss the challenges faced by the communities and possible solutions to increase social cohesion, and they highlight the public services and formal and informal businesses available to residents to increase awareness regarding existing life-supporting systems (Ziervogel *et al.*, 2016). Mobile applications can also support educational efforts for building capacities to prepare for, cope with and recover from disasters (**box 8**). Digital games are an additional technological tool for building resilience. For example, Extreme Event is an interactive role-playing game in which participants must build community resilience in the face of disasters by working together to make decisions and solve problems during a fast-paced disaster simulation.[33] Game-like programmes have also been used in computer simulation-based training for emergency responses (Pan *et al.*, 2015).

Box 8 Austria: Use of mobile applications for capacity-building in disaster prevention

As part of the project “Young Crowd”, teachers, students and interested young people use an application to expand their knowledge and discover existing resources on disaster prevention in their environment. The data they collect serves to plan further experiments and general research in crisis prevention. Implementation of the project is closely linked to cooperation with citizen scientists. By collecting data, they contribute to general research in crisis prevention, thereby developing new awareness of security and disaster risk management issues. In addition, citizen scientists use the application and report on their experience in its use.

Source: Based on a contribution from the Government of Austria.

b. Assessing, monitoring and managing risk

Reducing threats entails the ability to assess and monitor risks. One way to monitor environmental risks is to use sensor networks. In this regard, new developments in low-cost open-source hardware make it possible to develop ad hoc sensors that can complement existing but often sparse monitoring networks in developing countries.[34] An example is Arduino, a hardware platform and online user community for the manufacture of microprocessors and other low-cost electronics items, which have been used over the past decade by scientists and citizens to build systems that sense various environmental phenomena. Arduino kits and their derivatives have played a major role in the process of democratizing science, as ad hoc sensors can be constructed and programmed simply and on-the-fly. Another example is the project luftdaten.info by OK Lab Stuttgart, in which volunteers worldwide install self-built gauges on an outside wall of their homes to generate and transmit data to update fine dust maps. Citizens operating such sensors can also provide additional information via various devices such as smartphones.

Such crowdsourced information is commonly known as volunteered geographic information, and can take the form of time-stamped and geolocated photographs, social media updates or interviews and feedback to ad hoc hazard mitigation websites.[35] The combination of in situ sensors with volunteered geographic information can significantly improve the coverage of monitored areas, supporting resilience-building at the community level.[36]

Smartphones equipped with sensors (e.g. transceivers, frequency modulation and GPS receivers, cameras, accelerometers, digital compasses and microphones) can also be utilized for monitoring and scientific observation.[37] For example, the standardization of accelerometers in smartphones, combined with advances in cloud computing, has enabled citizen seismologists, who feed data into early warning systems for earthquakes, e.g. providing measurements of shaking magnitude and location and cursory analyses of initial seismic waves (Liang *et al.*, 2015).

In addition to in situ sensors, environmental monitoring is also conducted via remote sensing using satellites or drones. Satellite technologies are critical for disaster preparedness and emergency response. Small-scale satellites may soon be affordable in more developing countries and by businesses and universities, which would increase the reach of communications networks and applications that use high-resolution imagery, such as for monitoring land use and for urban planning (Buscher and Brieß, 2014). Drones offer a low-cost approach to remote sensing. They transmit images of the Earth’s surface in real time that, when combined with GPS data, can be exploited to populate land-use databases as well as assessments of disasters such as floods or of earthquake damage. They also have applications for rapid mapping in the event of an emergency, for example, when used with crowdsourcing platforms that tag live footage from aerial vehicles flown during disasters (Salisbury *et al.*, 2016). Environmental monitoring helps generate risk assessment maps. Digital technologies

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[33] See https://www.koshland-science-museum.org/extreme-event/.

[34] See, for example, Malakar, 2014; and Rieger, 2016.

[35] See, for example, Baum et al., 2014; Lane et al., 2011; Mee and Duncan, 2015; and Robson, 2012.

[36] See, for example, Buytaert et al., 2014.

[37] See, for example, McCabe et al., 2017.

have been used to produce maps with crowdsourced inputs from citizens, such as through Youth Mappers and through Community Maps, a platform of the Mapping for Change initiative that offers a range of participatory mapping services to Governments, community groups and businesses.

A critical component of community resilience is the existence of local early warning systems connected to national systems. For example, in the United States, local authorities disseminate emergency alerts received from the integrated public alert and warning system of the Federal Emergency Management Agency. Mobile technology introduces new possibilities for early warnings (**box 9**).

Box 9 Philippines: Surveillance in Post Extreme Emergencies and Disasters system

A strong health information system is crucial to an effective health emergency response, to detect trends in diseases and the provision of health services. An effective information system needs to be matched with a well-functioning health system, essential to saving lives and responding to the number of people who need care.

Surveillance in Post Extreme Emergencies and Disasters is a mobile-based early warning system to detect common health conditions in an emergency. It was developed by the Department of Health of the Philippines with support from the Australian Agency for International Development, the Government of Finland and the United States Agency for International Development, as well as technical guidance from the World Health Organization. The system uses mobile telephone technology to send reports on more than 20 disease syndromes and health events commonly seen during a health emergency. Information from first-line health workers and volunteers is sent to a central database that can be immediately accessed by health authorities at different levels to detect common health conditions in an emergency.

The system has been used in several emergencies in the Philippines and there have been no significant challenges. The system has also been adapted for use in Japan.

Source: Based on a contribution from the World Health Organization (see http://www.wpro.who.int/philippines/areas/emergencies_disasters/speed/en).

c. Responding to emergencies

Emergency response requires timely two-way communications for coordination and action. Mobile technology offers new possibilities for passing on information during an emergency, for example, the use of smartphones by rescue and relief workers to form a peer-to-peer communications network during an emergency and the use of mobile wireless local area networks with a series of wearable routers if pre-existing communications infrastructure is not available (Bandyopadhyaya and Mukherjeeb, 2016; Hacketta and Bilén, 2016). Mobile technology can also be used to conduct interactive post-disaster surveys for damage or needs assessment using text messages (Basu *et al.*, 2016). An example is the vulnerability analysis and mapping project of the World Food Programme to collect food security data in insecure or inaccessible areas through short mobile telephone surveys, using text messages, live telephone interviews and an interactive voice response system.

A relatively new phenomenon in disaster management is the use of social media. When disasters unfold, citizens immediately turn to the social media platforms they are most familiar with to both seek and share information (Edwards, 2009). Social media is used by local agencies in emergency management to involve community members as first-line informants and as first responders (Díaz *et al.*, 2016). Social media also creates shared awareness and commits citizens in new ways to increasing resilience (Hokkanen, 2016). States, localities, non-governmental organizations and agencies usually monitor social media feeds for relevant situational awareness, including patterns of serious needs, available resources and deployed responses.

New developments in data analytics and big data can also support emergency responses. For example, during a typhoid outbreak in Uganda, the Ministry of Health used data mapping applications to allocate medicine and mobilize health teams (United Nations Global Pulse, 2015). Data analytics and big data also make external assistance to communities more effective. An example is the World Health Organization emergency dashboard, which allows for the monitoring of health emergencies globally to inform action, including engaging a community's resources to prevent, prepare for, respond to and recover from health emergencies, such as the outbreaks in 2018 of Ebola virus disease in the Democratic Republic of the Congo and cholera in Zimbabwe.

During emergencies, the delivery of supplies is critical but often impractical, due to collapsed infrastructure or dangerous situations. In such contexts, drones could revolutionize the delivery of such supplies and replace humans in carrying out hazardous tasks. Small quadcopter drones are being employed for an increasing number of tasks, including the commercial delivery of packages and the delivery of high-value items such as vaccines to rural areas in developing countries. For example, in Rwanda, to address maternal mortality, the Government has partnered with a robotics company to use drones to deliver blood to medical facilities, reducing the time needed to procure blood from four hours to 15 minutes (Rosen, 2017). Drones can also be used for the regular delivery of supplies in remote areas (**box 10**).

Box 10 Canada: Moose Cree First Nation to receive drone deliveries

The Moose Cree First Nation has signed a commercial deal with a drone delivery company to transport supplies, medicine, food and mail from the nearest mainland town, Moosonee, starting in 2019. Moose Factory island is only accessible by boat in summer, ice road in winter and helicopter at other times. The service is designed to be affordable and fast; drones will have a 5kg maximum payload for the roughly 10-minute journey across Moose River. The objective is to serve communities that lack infrastructure, where basic goods are difficult to obtain or expensive, and to create employment for community members. In addition to delivering supplies, the drones can help with monitoring seasonal changes, such as river break-ups in the spring.

Source: BBC, 2018.

2. BUILDING ECONOMIC RESILIENCE

a. *Economic opportunities and diversification*

Resilient communities should be able to generate enough and diverse occupations to employ people and to better adapt to changes in employment and the outputs of different economic sectors due to technological progress, changes in consumption patterns, supply and demand shocks and changes in international interrelations that affect patterns of specialization and trade. Economic diversification is a commonly pursued strategy for coping and adapting in communities that need to manage fluctuations in resource abundance and seasonal cycles of economic activity or resource use, particularly in rural, tourism-based and coastal fishing communities.[38]

STI are critical in this process. Diversification is ultimately the result of innovation, that is, the introduction of a new sector in the economy. New sectors use labour and capital-embodied technologies in production. Such technologies do not need to be new. Instead, they may be, and in most cases are, traditional and well-tested technologies that are used in other places. Economic diversification remains a challenge for poorer economies with low levels of productive capacities. In more technologically advanced communities with broadband Internet connectivity, modern ICT and new technologies such as artificial intelligence, big data and three-dimensional printing could enable and support the development of innovative new sectors. For example, three-dimensional printing allows for small batch production and leads to free-form product design, as well as sustainable manufacturing.[39] It also shifts the location of production processes closer to either the designer or final consumer. At the same time, casual three-dimensional printers require considerable training in the use of the technology and, in many cases, are dependent on printing centre operators to develop the products.[40] Some of the new sectors could be introduced by creative workers (e.g. those in arts and entertainment) relocating to well-connected rural regions and using new digital technologies in cultural activities in and for their communities.[41]

Economic diversification can also be the result of innovation in labour-embodied technologies (e.g. in know-how, methods, procedures, norms and regulations). For example, changes in social norms that prevent access by women to productive resources, including restrictions in accessing capital for expansion and the need to reconcile business with domestic activities, could unleash women's potential and aspirations for growth and the creation of new businesses.[42] In other instances, the diversification of livelihoods in rural households may entail the migration of young household members, mostly women, to work in light manufacturing (e.g. textile, garment and leather industries) in urban and peri-urban areas, and their remittances become critical to sustaining the traditional and rural social and cultural way of life of their communities.[43]

b. *Access to energy and communications infrastructure*

Access to infrastructure such as electricity and communications is critical for community development and resilience (UNCTAD, 2018). Rural and remote areas are often underserved due to the higher costs of extending such infrastructure. New technologies can offer an alternative solution to costly investment in infrastructure related to traditional technological paradigms. For example, rapid technological advances and associated cost reductions in ICT in recent decades have enabled some developing countries, notably in Africa and Asia, to skip the development of analogue landline infrastructure by moving directly to digital mobile telecommunications. Several countries that had low levels of penetration of fixed and mobile telephones in the early 2000s had, by 2017, reached levels of subscriptions of mobile cellular telephones per 100 inhabitants above the global average (108.9), for example, the Gambia, Côte d'Ivoire, Ghana, Nepal, Timor-Leste, Cambodia and Mali (figure 4). These are successful examples of leapfrogging into digital telephony and the same pattern is seen in most developing countries. In 2017, developing

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[38] See, for example, Adger et al., 2002; and Marschke and Berkes, 2006.

[39] For a review of the literature, see Khorram and Nonino, 2017.

[40] See, for example, Hudson et al., 2016.

[41] See, for example, Roberts and Townsend, 2016.

[42] See, for example, Della-Giusta and Phillips, 2006.

[43] See, for example, Bouahom et al., 2004.

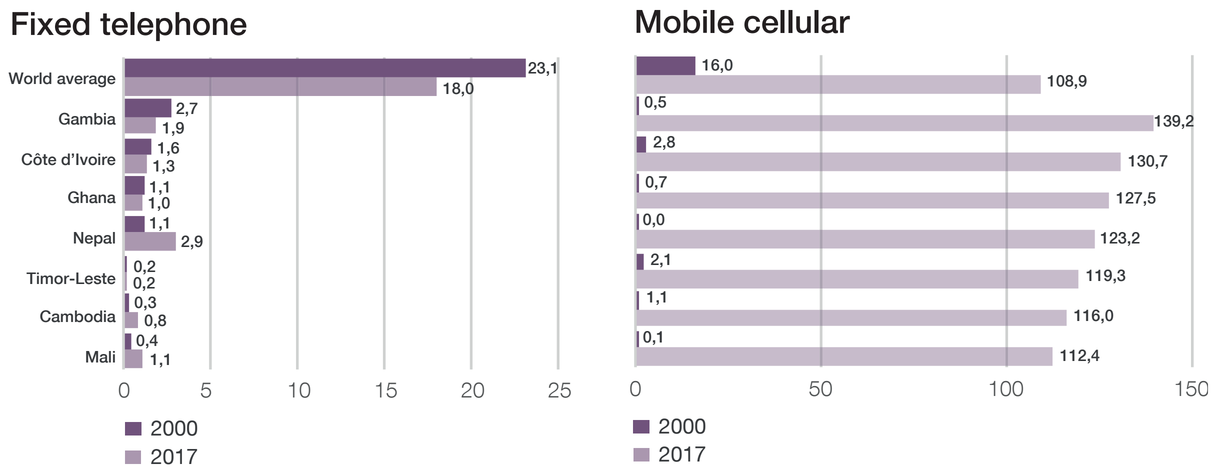
countries had a penetration rate of mobile cellular telephones of 98.7 subscriptions per 100 inhabitants, while the rate for fixed telephones was 8 subscriptions per 100 inhabitants (UNCTAD calculations, based on data from the International Telecommunication Union).

An example of the potential of new technologies to extend access to electricity is the development of decentralized renewable energy systems (UNCTAD, 2017b). For example, an analysis using geospatial data shows that to bring electricity to all households in sub-Saharan Africa by 2030, the most cost-effective mix of conventional and renewable energy technologies for several countries would be off-grid and mini-grid solutions using solar photovoltaic technology. Such solutions could provide a large share of the population with lower costs in Malawi (84 per cent of the population), Chad (83 per cent), the Niger (80 per cent), Burkina Faso (78 per cent), Mali (74 per cent), Ethiopia (73 per cent), Zambia (72 per cent), Lesotho (67 per cent), the Central African Republic (62 per cent), Zimbabwe (60 per cent), Mauritania (57 per cent) and South Sudan (53 per cent) (figure 5). In many cases, a higher electrification gap is associated with a higher potential for leapfrogging (i.e. countries to the right-hand side in the figure). The exceptions are due to factors such as a higher population density close to existing or already planned national grids, which reduce the need for off-grid and mini-grid solutions.[44]

c. Financial inclusion and risk financing

A critical element of a resilient community is the capacity of people to continue to have access to products and services after a shock. Financial services enable and facilitate this process, but many rural and remote areas, as well as vulnerable groups, are underserved due to the high costs of extending financial branches to these areas and handling small transactions. However, the rapid adoption of mobile technology has paved the way for innovative financial technology services such as the M-Pesa mobile banking system and the Grass Roots Bima insurance company in Kenya and the Flutterwave company for technology and infrastructure for large financial institutions in Nigeria, with important implications for financial inclusion (H2 Ventures and KPMG, 2017). For example, countries in sub-Saharan Africa have the highest percentages of adults who have a mobile money account, with a regional average of 21 per cent in 2017, compared with the global average of 4 per cent. The following countries take the lead in mobile financial inclusion, with over a quarter of the poorest 40 per cent of adults reporting that they have personally used a mobile account service: Kenya (59 per cent); Uganda (40 per cent); Zimbabwe (40 per cent); Gabon (37 per cent); Ghana (32 per cent); the United Republic of Tanzania (30 per cent); Namibia (29 per cent); Côte d'Ivoire (27 per cent); and Senegal (27 per cent) (UNCTAD calculations, based on the Global Findex database).

Figure 4 Countries that have skipped fixed telephony and moved directly to mobile communications



Source: UNCTAD, 2018b.
Note: Earliest data for Timor-Leste is for 2003 and latest data for the Gambia and Mali is for 2016.

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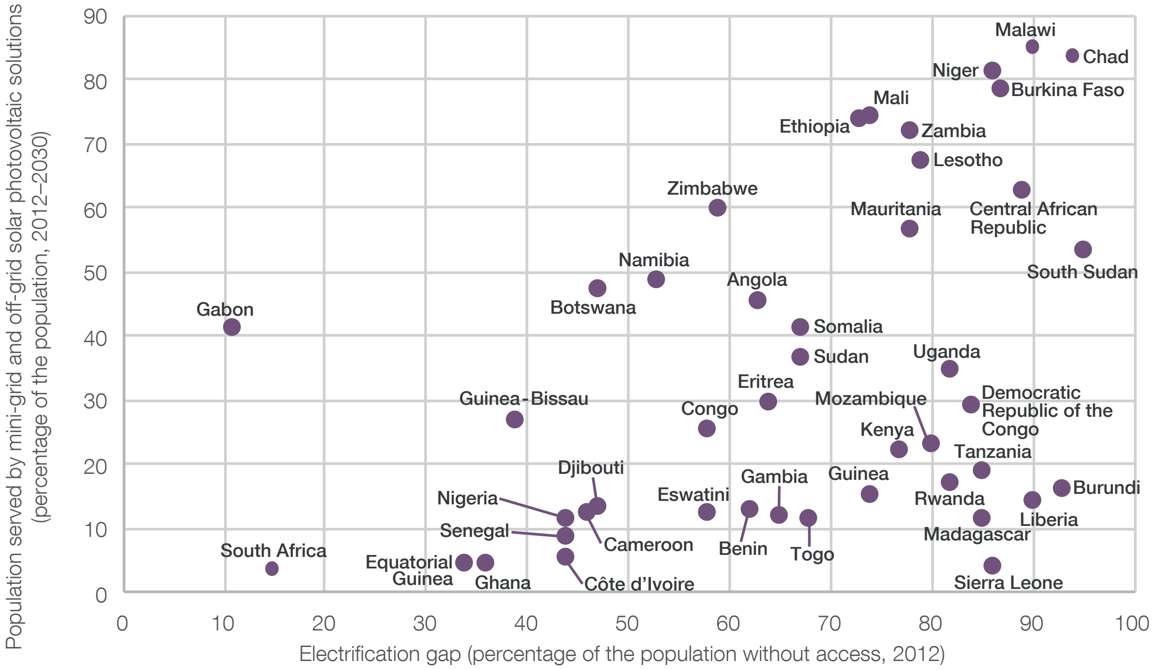
[44] For a discussion of the results of the model in selected countries, see Nerini et al., 2016.

Figure 5 Potential for leapfrogging in decentralized solar photovoltaic solutions



Source: UNCTAD, 2018.
Note: The electrification scenario considers 22kW hours of electricity consumption per household per year, grid electricity costs of $0.1 per kW hour and a price of $0.7 per litre for diesel fuel.

In addition to financial inclusion, there is also a need to expand the provision of and access to ex ante disaster risk financing tools such as insurance, microinsurance and catastrophe bonds, to better protect livelihoods against different kinds of weather-related shocks, such as droughts and floods. Some innovations in weather-related insurance, such as index insurance, have benefited the poor in lower-income countries in which rural and agricultural financial markets are underdeveloped. Index insurance makes payments based on an objective index, such as rainfall measures, that serves as a proxy for losses to crops. Insurance companies use satellite imagery and computer models to create indexes as the basis of payments.[45]

Satellite data complements rainfall estimates through in situ observations. In areas in which such observations are not available, satellite data is the only reliable source of information. They produce satellite-derived estimations of precipitation or vegetation greenness or health, as well as other information such as satellite-derived multisensor soil moisture.[46] Such data provide valuable inputs in index insurance, but require operational, quality-controlled, multisensor data sets, such as the soil moisture data set generated via the climate change initiative of the European Space Agency.[47] Such technologies could also provide early warning based on the relationships between climate variability, vegetation coverage and crop yields at multiple lead times. This could allow for ex ante cash transfers during a crop growing season, when the results of the index can already predict losses to crops, as opposed to ex post cash transfers after harvesting. Such an early response could result in significant cost savings (Guimarães Nobre *et al.*, 2019). Weather index insurance is also used for livestock, which are also affected by droughts.[48]

Despite the clear benefits of weather index insurance for increasing economic resilience among the poorest rural communities, uptake remains low in developing countries, in particular in sub-Saharan Africa, even in pilot initiatives. Some of the reasons are poor understanding of the concept of crop insurance, inability to pay premiums, rigid enrolment criteria, low levels of trust in insurance providers and past

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[45] See, for example, Skees, 2008.
[46] See, for example, Enenkel et al., 2018.
[47] See, for example, Enenkel et al., 2016; and Enenkel et al., 2017.
[48] See, for example, Vrieling et al., 2014.

failures of insurance models to properly estimate previous losses, reflecting a failure to involve farm households at the initial conceptualization and design of pilot initiatives.[49]

3. BUILDING ENVIRONMENTAL RESILIENCE

a. *Natural resources management*

The management of natural resources is critical for resilience, given that terrestrial and marine ecosystems provide, among others, food, water, medicine, energy, transport, construction material, shoreline stabilization, coastline protection and erosion prevention, climate regulation, oxygen production and for the maintenance of biodiversity, as well as recreation opportunities and aesthetic and spiritual benefits. Ecosystems provide a vital basis for the livelihoods of rural and coastal communities, particularly resource-dependent communities in developing countries. For example, satellite imagery and machine learning algorithms can be used for forest monitoring by tracking changes in tree cover and canopy density. Artificial intelligence may be used to cross check information on logging licences with data provided by geospatial mapping systems to monitor illegal logging (Claassen *et al.*, 2018). Drones have various applications in land and resource management, including land use dynamic monitoring, land law enforcement, land development and consolidation and real estate registration (Xiao and Chen, 2017).

With regard to the oceans, marine science and its supporting technologies can make a major contribution to improving ocean health and promoting the use of the oceans and their resources in sustainable development. Marine science plays an important role in the fisheries management process, including for the adoption of conservation and management measures (United Nations, 2010). Geospatial technology has a unique role in efficient water use practices and the conservation of bodies of water and infrastructure. Emerging technological trends include new remote sensors for measuring water cycle components, ground sensor-based field instruments, cloud-based data integration and computational models and geographic information system-based water information portals.[50] The Internet of things also offers innovative alternative solutions in several areas, including in water management and quality (Dora, 2015). For example, in Bangladesh, the Internet of things is being used to assess groundwater chemistry and protect people living in the Ganges delta who face the threat of drinking water contaminated with arsenic, reducing the need for investment in the implementation and maintenance of traditional monitoring networks (Zennaro *et al.*, 2008).

b. *Sustainable tourism*

Sustainable production and consumption contribute to community resilience by helping to preserve the environment. They also introduce new opportunities for innovative niche products and services, such as nature-based tourism, that promote a balanced interaction with nature, while also contributing to economic diversification. Such activities usually require more knowledge than those applied in traditional sectors and it is critical to build the capacity of community members to ensure meaningful engagements (**box 11**).

Box 11 Kenya: Kimana Ecotourism Project

Kimana Ecotourism is a wildlife-based ecotourism project started in 1996, in which the people of Kimana have sought to exploit the commercial advantage of their communal land, which lies near Amboseli National Park in southern Kenya. The Kimana Community Wildlife Sanctuary represents an example of a community-based ecotourism project that promotes the ideals of local participation in wildlife management and creates opportunities for the local Maasai pastoralists to benefit from wildlife tourism. The main goal is to conserve biodiversity as a source of earning foreign exchange, employment and training opportunities for the people of Kimana. In addition, the project seeks to encourage the community to participate in conservation through the establishment of locally owned small-scale wildlife-based ecotourism projects as a form of commercial enterprise.

To help attract tourists, the game sanctuary was fenced using donor funds, human resources were trained and hired, access through the road network was improved, a luxury hotel was constructed and neighbouring game lodges were involved in marketing and leading tourists to the sanctuary. The local community gives game rangers feedback on wildlife movement, migration, water sources and grazing grounds, among others, using mobile telephone technology.

The Kimana conservancy community lacks the required skills for meaningful engagement. Despite agreements that most conservancy staff would come from Kimana, only a few low-wage seasonal unskilled and manual jobs, such as those of security guards, rangers, porters, construction workers and cleaners, were made available to local residents. Most of the skilled positions, such as those of managers and drivers, were filled with employees transferred or sourced from other areas. In addition, due to illiteracy in the community, harnessing mobile telephone technology as a tool for citizen science is a problem.

Source: Based on a contribution from the Government of Kenya.

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[49] See, for example, Fonta et al., 2018; and https://www.economist.com/finance-and-economics/2018/12/15/in-africa-agricultural-insurance-often-falls-on-stony-ground.

[50] See, for example, Thakur et al., 2018.

Modern ICT, as well as geospatial ICT applications that rely on the availability and use of spatial data, can support nature-based tourism and recreation by enabling and facilitating eco-friendly outdoor activities such as hiking, mountain biking and cannoning. This requires building digital skills among users (i.e. planners, managers and tourists) to enable them to fully benefit from the technology.[51] ICT is also used in viral, participative, interactive, networked and versatile marketing techniques to actively involve tourists, particularly members of Generation Y (roughly, those born in 1981–1996), in the culture of and activities related to their tourism destinations. In this context, a fundamental change is the rise of social media, which facilitates the search of travel-related information, reservation and booking of activities, evaluation and judgment of tourism destinations, receipt of travel advice and communications of mobility patterns. Social media and mobile connectivity can harness niche groups to create bottom-up social systems interested in sharing experiences, ideas and resources enhancing sustainable tourism.[52] These have potentially innovative applications, but the implications for sustainable tourism remain unclear.[53]

4. CHARACTERISTICS OF TECHNOLOGICAL SOLUTIONS

Effective solutions for building the resilience of communities using market-ready new technologies are multipurpose, easy to learn and use, scalable and replicable, and are becoming ever more accessible (International Federation of Red Cross and Red Crescent Societies, 2015).

Multipurpose means that such solutions use technologies that are relevant and useful before, during and after emergencies, as well as in daily life. Clear examples are mobile telephone technology and smartphones, which are employed in solutions from disaster risk assessment and monitoring to emergency responses and early warning systems.

Technological solutions should be easy to learn and use. For example, this is a characteristic that makes social media useful in emergency responses, as there is no need for formal training and most people with access to a computer or smartphone can use such media. In the context of sensor networks, dedicated smartphone applications have been developed to collect relevant volunteered geographic information in a way that is easy to use.[54] In the use of drones for remote sensing, the simplification of their operation and data formats has allowed non-scientists to conduct surveys themselves, which has been shown to stimulate interest and enthusiasm in the objectives of resilience-building, when real-time aerial imagery of a community is viewed, often for the first time (Johnson *et al.*, 2017).

Technological solutions for community resilience should also be scalable and replicable and should grow to accommodate demand. The use of social media in emergency response provides scale and enables users to reach a large audience.

Technological solutions should be accessible, open, inclusive and increasingly affordable for consumers. This is another characteristic of the use of mobile telephones in emergency response, as they have become more available at lower costs. In the use of complex technological solutions, such as early warning systems or data analytics for emergency response, the increasing accessibility of data repositories and the online sharing of results make it possible to access and combine different data sets in novel, simplified and user-friendly ways. Advantages in the use of drones include the low cost of operation, which allows for frequent missions, increased spatial coverage, rapid deployment and the fact that no installation points are required (Vousdoukas *et al.*, 2011). With regard to renewable energy technologies, international prices in renewables have fallen significantly in recent years as investments in their development have increased. Since 2009, the cost of wind turbines has fallen by nearly one third and that of solar photovoltaic modules by 80 per cent, making both increasingly competitive with fossil fuel generation (International Renewable Energy Agency, 2016). Cost reductions represent an opportunity for electrification in rural areas, in particular in developing countries, through off-grid and mini-grid solutions.

Many of the characteristics of such technological solutions are enabled by ICT and the possibilities that ICT brings through digitalization and connectivity. ICT is facilitating ease of use and bringing significant reductions in costs, resulting in the democratization of access and the emergence of new actors and forms of innovation.

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[51] See, for example, Hennig, 2018.

[52] See, for example, Dickinson et al., 2017.

[53] See, for example, Gössling, 2017.

[54] See, for example, Mee and Duncan, 2015.

5. SKILLS REQUIRED TO USE, ADOPT, ADAPT AND MAINTAIN TECHNOLOGY

Many of the technological solutions highlighted in the previous sections are developed and implemented in communities in developing countries by experts or researchers from outside these communities. The sustainability and scalability of such solutions require that people within a community be able to adopt, adapt and maintain these solutions. In the context of new digital technologies, this requires a set of skills to adapt and creatively use available technologies and skills to innovate based on adapted technologies. This usually includes basic education and literacy, as well as familiarity with technological devices, and may include basic computing skills and familiarity with basic algorithms, digital mapping, remote sensing and low-cost sensor network hardware and software. The maintenance of technological solutions for building community resilience requires, in addition to basic ICT programming skills, other skills to assemble and combine technological devices, replace parts and components and adapt off-the-shelf parts. In addition to such technological capabilities, entrepreneurship skills are critical in turning innovative technological solutions into products and services available in markets or provided through public services. Social entrepreneurship skills are needed to develop, fund and implement solutions with the resilience of the community as the main goal.

D. INNOVATION: A MISSION-DRIVEN APPROACH TO RESILIENCE

Innovation results in products and services available to citizens through market mechanisms or public provision. Given the broad scope of areas related to resilience-building, most innovations that increase people's capabilities (e.g. in food and nutrition, health, education, housing, transport and communications), as well as those related to enabling technologies such as ICT, could be considered as contributing to community resilience. This study focuses on a subset of these innovations, namely, those that explicitly address the resilience of communities. This section discusses the state of innovation activity, the systems of innovation that characterize this innovation process and new approaches for innovation towards resilience that are enabled by digital technologies.

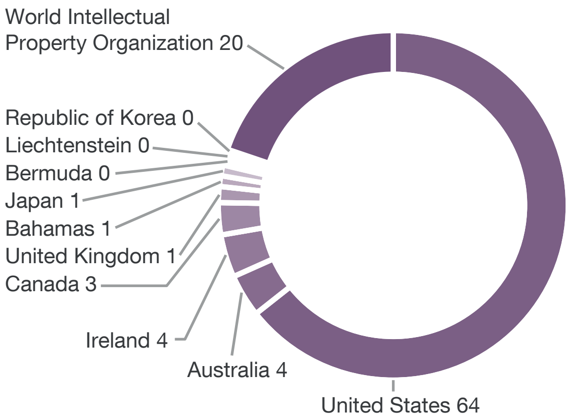
1. INNOVATION ACTIVITY FOCUSED ON BUILDING RESILIENT COMMUNITIES

Private sector and research institutes do not have demand-based incentives to pursue innovation with the explicit goal of building the resilience of communities. This is highlighted by the low number of patent applications explicitly related to community-based resilience and risk reduction, suggesting a lack of interest or incentives to engage in invention with this single goal. For example, since 1998, only 18 patents have been filed that explicitly mention resilient communities.[55] If patents related to community-based disaster risk reduction are included, the number rises to 202 patents since 1995. The number of patent applications per year was in single digits before 2007 and has recently varied at around 12 applications per year (figure 6). That number is marginal, considering that over 3.1 million patent applications were filed in 2016 alone.

Figure 6 Trends in the number of patents

Applications

Assignee (percentage)



Source: UNCTAD calculations, based on data from the Pat Snap data and analytics platform.

Similarly, an analysis of the technologies listed in the Green database, an online marketplace established by the World Intellectual Property Organization, shows only 12 listings that mention resilience as one of their characteristics or objectives, covering uses such as intelligent grid technologies and a tree support device for planting in the Sahel region. These technologies are in the areas of energy (7), farming and forestry (3), green products (1) and pollution and waste (1) and are sourced from the United States (4), Israel (2), Australia (1), China (1) and the Niger (1); seven of them at a usable level and only two with a proven record of commercial use. An analysis of listings of technologies in the "Technology4SME" database of the Asia-Pacific Centre for Transfer of Technology and the Economic and Social Commission for Asia and the Pacific shows 15 technology offers to address disaster situations in the areas of energy (5), emergency response (5), construction (2), early warning (2) and water (1), in uses such as portable solar-powered system for disaster relief and tsunami disaster alert systems. This relatively low number of inventions and

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[55] UNCTAD calculation, based on data from the Pat Snap data and analytics platform.

innovations is comprehensible considering that resilience is not an easily defined objective. Commercial research and development efforts focus instead on concrete issues such as communications, construction and health, which have a clear demand, while also contributing to resilience. As a result, many innovations for building the resilience of communities are mission-driven ad hoc solutions for specific situations.

Mission-oriented innovation involves organizing networked research programmes at the national or international levels, as well as incentive structures that can direct innovation towards the achievement of specific technological, environmental or social goals. A recent and successful example of a grand challenge was in response to the outbreak of Ebola virus disease in West Africa in 2014, for which the United States Agency for International Development received over 1,500 submissions from innovators around the world with ideas to improve infection control (United States Agency for International Development, 2015). Contemporary mission-oriented innovation programmes range from national to international and private foundation to public and private-sponsored initiatives, of varying but often substantial scales, and may incentivize the creation of technological solutions through innovation prizes and advance market commitments.

2. INNOVATION SYSTEMS FOR BUILDING RESILIENT COMMUNITIES

Innovations are the result of the complex interrelations of various actors (e.g. firms, research and education systems, Governments, civil society and consumers), the connections among them and the enabling environment for innovation that they create. These elements characterize systems of innovation.

Innovation systems for the creation of products and services for building resilient communities are usually mission-driven, meaning that actors in the systems pool resources to solve a particular social problem, for example, the need for early warning against hazards and for functioning communications networks during an emergency. Such innovation systems usually focus on the later-stage deployment of traditional technologies (e.g. vaccines and remote sensing) or market-ready new technologies (e.g. smartphone applications and low-cost drones), in contrast with early-stage exploration and the development of emerging technologies (e.g. artificial intelligence and CRISPR).[56]

Key actors in such innovation systems are local and national governments, civil society organizations, education systems, social entrepreneurs and citizens, as follows:

- National Governments are key to providing direction for the mission-oriented approach to innovation and the required hard and soft public infrastructure, promoting capacity-building and fostering the creation of linkages in an innovation system;
- Local governments have a clear role to play in the provision of local public services and goods that increase resilience, e.g. education, health, transport and infrastructure against floods (Howarth and Brooks, 2017);
- Civil society organizations are important intermediaries between the producers of scientific knowledge and related technologies and households in communities, and they can assist in educating and supporting individuals in several aspects of resilience-building (Fitzpatrick and Molloy, 2014; Howarth and Brooks, 2017). They can mediate between local governments, technology developers and marginalized groups, and promote innovations that address their needs. In many countries, they can be instrumental in testing, promoting and diffusing innovations designed to benefit the most disadvantaged communities. They also play an important role in disseminating good practices and lessons learned in the design and implementation of STI solutions for community resilience-building. Finally, they can mediate between the State and citizens in citizen science initiatives to increase the transparency and accountability of the State in the provision of public services (e.g. water and sanitation);[57]
- Effective education systems increase the capacity of communities to learn, adapt to changes and contribute to the innovation process of finding new and better solutions to the challenges of disaster risk reduction and the Sustainable Development Goals. Science-related communications are important in increasing the capacity of communities to use existing knowledge;
- Social entrepreneurs contribute to the innovation process by providing local solutions in response to local social, cultural and environmental problems (Berno, 2017). They help build resilient communities by addressing existing vulnerabilities and promoting sustainable transitions;

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[56] Clustered regularly interspaced short palindromic repeats.

[57] See, for example, Georgiadou et al., 2014.

- Citizens are the final users of many of the products and services for building resilience. They contribute with inputs on the effectiveness and usability of such solutions.

Effective innovation systems have robust and evolving linkages among all such STI stakeholders, such as cooperation between science and technology groups and educational institutions to promote the popularization and dissemination of resilience-related knowledge and self and mutual rescue skills; and to foster educational resources for disaster risk reduction. Another link is cooperation between science and technology groups and Governments, communities and other stakeholders to promote the popularization and application of scientific knowledge and technological solutions (**box 12** and **box 13**).

Box 12 South Africa: Developing a society knowledgeable about science

In 2015, the Department of Science and Technology adopted the Science Engagement Strategy to develop a society that is knowledgeable about science. The objective is to implement initiatives that target 11 designated sections of society: learners, educators, industry, scientists and researchers, science interpreters, decision makers, journalists, the general public, students, tourists and indigenous knowledge holders. The Department is also implementing a structured school-based science engagement initiative that includes the Globe Programme, which was initiated by the Government of the United States and connects students, teachers, scientists and citizens from different parts of the world to conduct real hands-on science about their local environment and put this in a global perspective.

Source: Based on a contribution from the Government of South Africa.

Box 13 United States: Making scientific findings and tools available to communities to enable resilience

Making scientific findings and tools available to communities to enable resilience is a federal priority. The Weather-ready Nation Programme of the National Oceanic and Atmospheric Administration is dedicated to quickly translating new science and technology into forecast maps and other tools that communities can use to prepare for extreme weather, water and climate events. They aim to help government officials, businesses and the public make decisions that save lives and property and enhance livelihoods. A cadre of weather-ready ambassadors help the Administration design and deploy their products. Similarly, the Community Resilience Programme of the National Institute of Standards and Technology translates scientific findings into tools and metrics to help communities develop strategies to achieve resilience. Stakeholder engagement is an important aspect of this programme, to ensure that the products developed are as useful and effective as possible.

Source: Based on a contribution from the Government of the United States.

An effective innovation system for building community resilience also requires an enabling environment. Infrastructure should be developed with a specific emphasis on ensuring affordable access to ICT and overcoming geographical, gender-related, generational and income-related digital divides. The regulatory and policy framework should provide a supportive environment to facilitate mission-driven and long-term planning by innovation actors. Coherence is needed between STI policies and policy areas such as public health and disaster risk reduction. The institutional setting and governance should engage the participation of the community in the design and implementation of resilience-building innovations. There should be flexible access to finance for social entrepreneurs through appropriate and readily accessible financial instruments. Human capital should be nurtured through a strong focus on building the required skills to use enabling technologies, such as ICT, and on the dissemination of resilience-related knowledge through the education system. Social and cultural norms and practices should promote the inclusive participation of women, youth and the elderly in the innovation process towards community resilience.

3. INNOVATION APPROACHES FOR COMMUNITY RESILIENCE

New technologies open opportunities to tap into the potential of large segments of the population in developing countries, including youth, who have not been considered in traditional innovation policies.58 This is why growing attention is being given to several new approaches to innovation. Such approaches are termed pro-poor, inclusive, below-the-radar, frugal, bottom-of-the-pyramid, grass-roots, mission-oriented and social innovation, largely reflecting differences in emphasis. They should also be considered in combination with innovation driven by the private sector in a more traditional sense (Fu *et al.*, 2014).

Pro-poor and inclusive innovation can increase community resilience by extending the benefits of innovation to previously excluded groups, either as consumers of new products and services or as participants in the innovation process. The focus is on developing low-cost products and services to serve untapped markets, such as low-cost medical products and mobile telemedicine clinics in remote rural areas; and innovations that offer possibilities for people living in poverty to engage in small trade to help raise their incomes. Several Governments and development institutions have supported pro-poor and

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[58] This section draws on UNCTAD, 2017a.

inclusive innovation through seed funding schemes for small producers, new financial services and infrastructure for the development of local markets and innovation in new products (UNCTAD, 2014).

Grass-roots innovation approaches seek to include local communities in the innovation process, which is critical for the engagement of community members in initiatives for building resilience. This is done through the involvement of grass-roots actors, such as social movements and networks of academics, activists and practitioners experimenting with alternative forms of knowledge-creation and innovation processes (Fressoli *et al.*, 2014). For example, community-based disaster risk reduction systems (e.g. risk investigation, education and training, landslide monitoring, information analysis, early warning systems and emergency response) usually engage the community in the development of monitoring and early warning mechanisms.[59] Another example is the development of innovative mobile payment solutions, in particular for consumers at the bottom of the pyramid, using basic mobile telephone technology rather than smartphones.[60] Grass-roots innovation initiatives operate in civil society arenas, driven by social and environmental needs rather than competitiveness or profit, based on mutual exchange, voluntary inputs from actors and local knowledge, often supported by grant funding.

Social innovation refers to innovations in social relationships, practices and structures that are primarily aimed at addressing social needs and at improving human well-being (Van der Have and Rubalcaba, 2016). Some examples of social innovation for building community resilience include the provision of microfinance products and services to reduce the financial vulnerabilities of communities at risk, the promotion of new local business ideas for the diversification of livelihoods and support for women's eco-entrepreneurship as an approach to sustainable local rural development.[61]

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[59] See, for example, Liu et al., 2016.

[60] See, for example, Gaur et al., 2014.

[61] See, for example, Pallarès-Blanch, 2015; Quaranta et al., 2016; and Ullah and Khan, 2017.

E. KEY CHALLENGES

1. TECHNICAL CHALLENGES: DATA AND UNDERLYING ENABLING TECHNOLOGIES

Several gaps persist in data used to inform resilience-building efforts in developing countries. For example, many sensor networks (e.g. river gauging stations and seismographs) remain highly time and cost-intensive to operate due to the temporally dense nature of monitoring and complex data download, processing and storage techniques. Moreover, their positioning in often harsh, remote and inhospitable environments hinders routine site maintenance. Given pressures on funding, the acquisition and management of such data have regularly been deprioritized, particularly in Africa, leading to large numbers of redundant or abandoned stations (Paul *et al.*, 2018).

Crowdsourcing data may be a solution, but many challenges must be overcome. In general, it is difficult to broadly share, validate and integrate crowdsourcing inputs into response operations and existing reporting channels. There are also misconceptions about the validity and veracity of crowdsourced data and in this regard, training and more practical experience for both users and policymakers could help. In addition, there is untapped potential for communities to leverage existing national crowdsourcing and citizen science projects before, during or after a disaster. For example, citizen science data, once collected, have the potential to plug such data gaps, particularly in remote areas, and to be used for further research, model calibration and validation or for the planning and design of future resilience-building programmes. The key word is potential. At present, many projects that exploit citizen science data, such as the European Union-funded We Sense It and Ground Truth programmes, exist only as proofs of concept (Horita *et al.*, 2005). Both projects aim to leverage crowdsourced observations to improve flood forecasting applications, yet note that operationalizing such new data acquisition strategies, for example in a disaster risk reduction environment, is not a primary objective.[62]

To better leverage such data, efforts should be directed at creating data standards and frameworks that facilitate the collection and dissemination of data. For example, an integral component of citizen science resilience-building projects typically involves sensor-sourced data collection by non-scientists, and the design of the sensor network may need to be technically simplified so that self-consistent samples can be taken (Buytaert *et al.*, 2014). Data conversion between technologies, platforms and applications would also increase the use of data. For example, the use of smartphones to photograph the extent of flooding and river levels has the potential to form a dense network of crowdsourced sensors, yet the data conversion to input for numerical models, as well as the provision of information back to volunteers, remains technologically demanding and in development (Karpouzoglou *et al.*, 2016).

An additional challenge is that such data are often of lower quality and more temporally sparse compared with the required for calibration and validation of numerical models that inform resilience-building against the effects of natural hazards (i.e. typically long-term high-quality time series). One solution has been to apply novel merging algorithms, for example between citizen science-collected rain gauge data and satellite precipitation products, to create combined data sets.[63] However, guidance on the deployment, use and management of such data collection services, particularly by those outside of the professional scientific realm, remains limited.[64]

Citizen science can overcome the challenges of high observation costs and limited spatial coverage of traditional monitoring networks, but the effects of decreased observational frequency, irregular availability and variable accuracy from sensor to sensor need to be quantified before the data can be used in numerical models. Uncertainties are a major bottleneck to the more widespread use and integration of citizen science data in, for example, operational early warning systems. Ideally, they should be characterized as explicitly and transparently as possible, for example by providing uncertainty bounds. These could take the form of approximate percentage errors on river levels as deduced with a smartphone camera or a basic quantification of bias if precipitation is recorded under suboptimal conditions. Despite rapid technological advances, citizen

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[62] See, for example, Solomatine et al., 2017.

[63] See, for example, Grimes et al., 1999; and Manz et al., 2016.

[64] See, for example, Lundquist et al., 2013.

science data are rarely presented in such a form due to inherent difficulties in uncertainty quantification.[65]

With regard to the use of social media for building resilience, some issues require consideration related to the reliability of information, matters of privacy and data protection and the nature of the content published in social media (Hokkanen, 2016). Data in general, when used in either humanitarian and disaster-related emergency contexts or preparedness contexts, raise the need for operationally responsible data approaches, as well as issues with regard to the tension between information sharing and data privacy (Chana *et al.*, 2016). In this regard, there is a need for the prudent use of data acquired during rapid land surveying in developing countries and for action to protect citizens' privacy (Haarsma and Georgiadou, 2017). Moreover, the choice of technology for a particular activity and the design of a suitable sensor network play a crucial role in decision-making in resilience-building (e.g. operational hazard forecasting, early warning systems for floods and water quality testing).[66] Several such projects have already successfully integrated participatory data collection as a means to expand the observational database in both space and time.[67]

Many top-down institutional research techniques have struggled to create actionable knowledge at a local level. For example, river level and discharge monitoring, as well as earthquake prediction, is usually based on a sparse network of gauges that require extensive and technologically complex maintenance, which confine them to large, well-funded institutions and official government entities. This restriction, together with the complexity of the data itself, often entails administrative and even legal issues over data access, which can frustrate community-level users.[68]

Linking data collection, analysis and information dissemination together via user-friendly online interfaces or applications is strongly advocated by the Sendai Framework for Disaster Risk Reduction 2015–2030. This process has been shown to support the citizen science approach, allowing tailored interfaces and people-centred decision and policy support systems to be constructed. Such technologies have been described as environmental virtual observatories, which allow information to flow freely between multiple actors.[69] Such observatories have only recently developed to highlight how data co-generation potentially leads to the political empowerment of marginalized individuals and communities. In this way, they have broad implications for resilience-building and knowledge co-creation in developing countries.

Another critical issue in the use of STI for building resilient communities is access to communications networks such as Wi-Fi or the Internet and equipment at the community level. For example, the citizen science approach emphasizes the benefits of using non-scientists as basic interpreters, placing a renewed focus on data logging, quality control and transmission. Web-based services allow for the easy connection of sensors with online modelling tools to provide real-time data quality control, storage and simulation. However, when individuals have access to equipment, as with mobile telephones, older smartphones may be prevalent in some demographic groups, regions and countries, which may not interface with the latest applications. From a technical perspective, regions with low levels of Internet penetration can benefit from far-reaching mobile telephone coverage for sensor data transmission via text messaging (Buytaert *et al.*, 2014). An important component of digital infrastructure is the availability of local business that can support and maintain such infrastructure, both hardware and software. Therefore, initiatives to foster and promote the ecosystems of local ICT firms are needed.

2. SOCIAL CHALLENGES: KNOWLEDGE GENERATION AND USE

Members of a community have different levels of resilience, which are influenced by actions and policies at the individual, local, regional, national and even international scales. Resilience is also affected by power relations within communities. Therefore, resilience is not uniform or neutral but reflects social norms and biases and the interests of different actors with competing motivations (Roberts *et al.*, 2015). For example, technological solutions for community resilience should take into consideration that women and girls are particularly at risk when it comes to the destabilizing effects of shocks such as natural hazards or the effects of climate change. Women often do not have equal access to technologies that can help families and communities build resilience. When women and girls have better access to climate-resilient resources and

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[65] See, for example, Davids et al., 2017; and Buytaert et al., 2016.

[66] See, for example, Banik et al., 2017.

[67] See, for example, McCulloch et al., 2008.

[68] See, for example, Paul et al., 2018.

[69] See, for example, Buytaert et al., 2016.

technologies, they can devote more time to activities (e.g. education, paid work, political and public participation and leisure activities) that enhance quality of life in entire communities. It is particularly important that women and girls be given an active role in designing and developing strategic responses to climate change. The resilience of communities improves by empowering women and girls, as shown by initiatives that build their digital skills and provide access to community technology learning centres, facilitating their access to jobs and fostering entrepreneurship (**box 14**).[70]

Box 14 Kenya: Angaza community project

The Angaza community project in the Kibera settlement in Nairobi targets the empowerment of women and youth through the following objectives: promote health education and enhance the prevention of disease and illness, including response to HIV and AIDS among the infected and affected; empower women and youth economically by equipping them with relevant skills and knowledge in microfinance and resource mobilization; improve literacy levels among children, youth and adults through support for formal vocational training; and provide referral services to the needy in the community. The project involves the public in data collection activities and encourages wider community engagement and provides important information on catchment management. The challenges faced by the project include the high incidence of poverty and increasing population growth. Kibera is estimated to be the largest such settlement in Africa, with a population of nearly 1.7 million people in a 3.2 km radius, and population density estimated at 3.3 square metres per person. Kibera has little or no infrastructure, with mud-walled houses and open sewers and drains and sewage and garbage dumps. It lacks adequate schools and hospitals to meet the demand. Although it is located in an urban area, Kibera lacks food, running water, decent housing and adequate electricity.

However, Kibera is an environment featuring small-scale business activities of every kind. The Angaza community project is working on developing entrepreneurship skills in the community to lift women and youth out of the cycle of poverty. In this way, the project contributes to addressing the Sustainable Development Goals and Kenya Vision 2030. Specifically, the STI component includes engaging the community in data and information gathering, as well as training in ICT, entrepreneurship and vaccine trials (e.g. for HIV, AIDS and malaria).

Source: Based on a contribution from the Government of Kenya.

In citizen science projects, volunteer recruitment and engagement throughout the duration of a project remain a challenge, with possible solutions including the development of a ranking system and the identification and promotion of particularly able volunteers. Another non-technical factor that affects the uptake of citizen science data, in particular in developing countries and the least developed countries, is that the proposals of non-scientist knowledge may not adhere to the often rigid institutionalized processes through which knowledge is collected, e.g. national networks of seismographs established with bilateral aid (Birkenholtz, 2008). Studies suggest a higher rate of success for initiatives that combine informal sanctions and rewards and their formal counterparts (Katomero and Georgiadou, 2018). However, when these mechanisms are not devised in a participatory way by all actors involved, it may be difficult for the proposals of non-scientist local stakeholders to feed into decision-making by national institutions such as agricultural or hazard response agencies.

Data collection is becoming increasingly multitiered, involving an increased diversity of actors, purposes and tailored, multi-objective networks. Such developments are sometimes precluded by cultural differences between scientists and local stakeholders (e.g. in language, customs, hierarchy, gender and the treatment of outsiders).[71] This could become more challenging when designing and implementing transboundary monitoring systems involving governmental and non-governmental actors across various political jurisdictions.[72] Poor social cohesion within communities themselves sometimes causes a lack of trust in the ability of a research project to achieve its stated goals. Issues with regard to people management and the large scale of some citizen science projects also have the potentially greatest negative impact on data quality and dissemination (Gura, 2013).

The way that knowledge is created and represented – its legitimacy and to what extent it is contested – is at least as important as the design of citizen science data collection activities themselves (Buytaert *et al.*, 2014). Moreover, many natural hazards and demographic-related data, such as on water consumption, have a financial aspect in a resilience-building context, which underscores the importance of economic value as well as political legitimacy. It is also critical for the data and generated knowledge to be, and be perceived as, locally relevant and actionable. To this end, the feedback loops between citizen science and decision-making should be clear and transparent at a variety of different levels, as they depend upon a profound understanding on the part of individual non-scientists of the generated information.[73] A major pitfall to be avoided is that citizen science-generated data remain unexploited (e.g. fed

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[70] See, for example, Khalafzai and Nirupama, 2011.

[71] See, for example, Solomatine et al., 2017.

[72] See, for example, Chandran et al., 2015.

[73] See, for example, Paul et al., 2018.

into numerical models) instead of being transformed into useful output for non-scientist stakeholders at the community level (e.g. hazard maps related to landslide or earthquake vulnerability), let alone communicated back to the affected communities themselves.

The standardization of tools and methods used in citizen science could also help reduce operational challenges to implementing projects. For example, initiatives such as CitizenScience.org and CitSci.org seek to harness the knowledge gained by practitioners and researchers across the field of citizen science to build collaboration, community and credibility. In some instances, a mismatch is reported between the amount of scientific knowledge produced to inform decision-making at the local level and the low demand for that information due to existing policy, legal and regulatory frameworks that do not entrust the responsibility for acting upon the information to the local government (Howarth and Brooks, 2017). A possible response is the decentralization of responsibilities in managing disaster risk reduction.[74]

The clash between how a typical research project or specific resilience-building intervention is perceived by the (usually western) professional scientific practitioners and the local stakeholders in the (usually poorer) country of interest has been noted as a major point of friction and inaction.[75] Scientists usually consider resilience-building as a discrete undertaking limited by funding. They often focus on publications and grants rather than sustainability and equity in development, and lack time and money to fully understand local languages and/or dialects, social norms and livelihood situations. At the same time, local stakeholders consider resilience-building as having a measurable impact on livelihood but lack trust or may bear a resentment if previous, often government entity-led, interventions have failed to produce tangible improvements. Confronted by these challenging views, citizen science projects in developing countries increasingly seek to fully involve local stakeholders, from the problem definition stage to data analysis and interpretation and to the final dissemination of results and information communications interfaces.[76]

Technology-driven citizen science projects to boost resilience should include a social science component rather than solely engineering or physical science components, as social scientists can usefully perform situational analyses of the communities at risk, to ensure that research project outcomes are actionable and have a measurable impact on local livelihoods. Furthermore, the establishment of regular scientist and local stakeholder meetings or workshops has been shown to surmount intracommunity cultural challenges and issues of trust.[77] The most effective such workshops include an additional element of training, ideally delivered by local project members in the local language, but under the scientific direction of the project leaders.

3. MARKET CHALLENGES: SCALABILITY AND SUSTAINABILITY

A critical challenge in innovation systems for building resilient communities is that many of the solutions are not developed beyond the prototype phase. The main gap is the move to service delivery models, improving the link between prototyping and entrepreneurs that bring the product or service to the market.

With regard to the use of hardware such as drones and sensor networks in community-led resilience-building, current operational deployments are of a relatively modest scale, rarely beyond the scale of small, isolated villages.[78] Some of the challenges are the limitations of off-the-shelf components that are usually not designed for the intended purpose of capacity-building; the lack of suitable sensors; and the cost of deployment and data collection, which remains high in areas of interest that are often remote and impoverished. Moreover, important application-specific requirements (e.g. variable sampling rates, well-defined and flexible sensor interfaces, ease of deployment and network models for the broader environment) may not be well catered for through the use of off-the-shelf components. Another challenge is the engagement and coordination of efforts across different governmental areas, sectors and markets (e.g. health, infrastructure and education), which are required to upscale solutions for resilience-building that usually have multiple impacts in different areas under the Sustainable Development Goals. For example, the sustainability of citizen science projects depends, in part, on the motivational factors of non-scientist stakeholders, which creates an added layer of uncertainty with regard to their sustainable integration in longer term capacity-building projects.

Recovery strategies implemented without a careful study of unintended consequences could also affect

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[74] See, for example, Malalgoda and Amaratunga, 2015.

[75] See, for example, Buytaert et al., 2014.

[76] See, for example, Paul et al., 2018.

[77] See, for example, Davids et al., 2017.

[78] See, for example, Kerkez et al., 2012.

resilience and can lead to increased social vulnerability. For example, in 2004, following the tsunami in the Indian Ocean, relief groups delivered new boats and fishing equipment to coastal fishing communities in Sri Lanka in such quantities that there were more fishing vessels soon after the tsunami than there had been before. As a consequence, vulnerability to fishery collapse increased in an area where fisheries were already considered stressed and where decreasing catches by subsistence fishers directly affects the main source of protein for many people (De Silva and Yamao, 2007; Subasinghe, 2005).

4. DEVELOPING RESILIENT SCIENCE, TECHNOLOGY AND INNOVATION SOLUTIONS

STI solutions should be resilient. Those focused on emergency response should be able to withstand weather, wear, pressure and damage. They should also be power efficient and increasingly leverage innovative sources of energy, supported by a network of redundant products and services with which they are interoperable. In this regard, the quality, design, distribution, interrelation and operation of technological infrastructure affect the resilience of the infrastructure itself, which has an effect on the resilience of people to economic, social and environmental shocks. By damaging infrastructure and its functionality, disasters also impact the socioeconomic fabric of communities. The disruption of critical infrastructure, such as hospitals, transport systems and electricity and ICT infrastructure, causes major negative effects on the economy and functioning of a society (**box 15**).

Box 15 Safe Hospitals Programme

The objective of the Safe Hospitals Programme is to safeguard health facilities and ensure that they are always functional, including in emergencies. If a health facility is assessed as unsafe, posing a threat to health or liable not to function in an emergency, based on the hospital safety index of the World Health Organization, retrofitting, for example, should be considered to improve its resilience.

In Nepal, for example, a study found that spending $150,000 on non-structural mitigation measures in nine hospitals to secure equipment and medicines made them better able to function following an earthquake. Following the implementation of such measures, when an earthquake measuring 7.8 on the Richter scale occurred in April 2015 and a second earthquake measuring 7.3 occurred in May, both failed to disrupt services at the largest public hospitals in Kathmandu. The Ministry of Health and Population of Nepal and the World Health Organization have had interventions in place for more than a decade to ensure that key hospitals, health facilities and health workers are able to withstand earthquakes and able to function well in an emergency.

Source: Based on a contribution from the World Health Organization.

The complex nature and high level of interconnectedness of much of the related infrastructure make them particularly vulnerable to chain reaction effects during a crisis.[79] The shape and structure of infrastructure networks affect how resilient they are against shocks. For example, many infrastructure networks tend to be formed by continuously adding new segments to existing parts of a network that are already well connected.[80] Such networks are robust with regard to random failure but vulnerable to failure on nodes with many links. Public transport networks, for example, seem to be robust with regard to random failure but vulnerable to more targeted shocks that disrupt nodes that are more connected or central and have the greatest influence on the available paths in the network (Berche *et al.*, 2009). Other infrastructure may also be affected in this way depending on its structure. For example, a review of studies of the robustness of power grids using complex network concepts found that most are robust with regard to random failure and vulnerable to targeted attacks on the most connected nodes. In this regard, strategies to improve robustness include restricted link addition, microgrids and smart grids (Cuadra *et al.*, 2015).

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[79] See, for example, Van Eeten et al., 2011.

[80] For a review of the literature, see Derrible and Kennedy, 2011.

F. SCIENCE, TECHNOLOGY AND INNOVATION POLICIES FOR BUILDING RESILIENT COMMUNITIES

STI policies for building resilient communities should focus on strategies and mechanisms that create an enabling environment for the mission-driven and late-stage deployment approaches that are characteristic of this innovation system. Such mechanisms differ from traditional policies. For example, a stronger emphasis should be placed on building capacity to use existing knowledge instead of the traditional focus on the generation of new knowledge. Policies should also foster the engagement of academic and civil society organizations with the private sector to facilitate the upscaling of solutions. Instead of the traditional emphasis on research and development, foreign direct investment and trade as sources of innovation and technological knowledge, the focus should shift to incubators (in more technologically advanced countries), accelerators, innovation labs and marketplaces, as well as new approaches such as pro-poor, inclusive, below-the-radar, frugal, bottom-of-the-pyramid, grass-roots and social innovation. In addition, policies should coordinate the provision of the required infrastructure for innovative community-based solutions, including national data and information infrastructure for resilience (**box 16** and **box 17**).

Box 16 Chile: Research and development and innovation strategy for resilience against disasters of natural origin

In 2016, the Natural Disasters Commission, under the National Council for Innovation and Development, proposed a national research and development and innovation strategy for resilience against disasters of natural origin, with a budget of $45.7 million per year. Under this strategy, it is expected that each year, on average, Chile will save up to $106 million through the lower level of losses associated with natural hazard disasters. The strategy is associated with the following five enabling conditions: a new institutional framework; a modern national data and information infrastructure for resilience; an advanced human capital development programme in the area of risk and resilience; the development of five national knowledge and manufacturing laboratories; and an outreach programme towards society based on the generated research and development and innovation.

Source: Based on a contribution from the Government of Chile.

Box 17 Japan: Resilience disaster information system

In Japan, as part of a cross-ministerial strategic innovation promotion programme, the Government developed a resilience disaster information system to share real-time disaster-related information between the public and private sectors and to estimate the damage immediately after a disaster. This was a five-year project in 2014–2018, with a budget in 2017 of ¥2.3 billion. The system will provide prediction solutions, including forecasting technologies for tsunamis, heavy rain and tornadoes. It will also support responses to natural disasters through ICT-based information-sharing and application technology, a disaster information collection system and a real-time damage prediction system, disaster information distribution technology and disaster response at the local level via regional cooperation application technology. The system will address prevention through liquefaction-response technologies based on large-scale verification tests.

Source: Based on a contribution from the Government of Japan.

Policies should also promote the development of firms providing services related to enabling technologies such as ICT (**box 18**). Given the complex nature of disasters, there is a need for policy to promote resilient ICT infrastructure to reduce the risk of natural hazards triggering technological disasters. In addition, STI policies should help build resilience against the potential negative economic, social and environmental effects caused by disruptive innovations, such as the potential impact on jobs in productive sectors that use automation, artificial intelligence and robots. This objective may be pursued through policies that promote the building of skills and productive capacity in frontier technologies, to increase societal readiness to adapt to innovations using these technologies. It is also important to build foresight capacity for the early detection of potentially disruptive innovations, which could help better target proactive interventions (**box 19**).

Box 18 Islamic Republic of Iran: Support for creating local services in information and communications technology

The Vice-Presidency for Science and Technology and the Ministry of ICT have several initiatives and incentives to support the establishment and expansion of ICT-based start-ups and small and medium-sized enterprises. Society and crisis are among the key priorities to receive support. The Vice-Presidency provides a variety of support under the law for supporting knowledge-based firms and creative and cultural industries council. The ICT Start-ups Empowerment and Facilitation Centre, an affiliated body with the Ministry of ICT, also has several initiatives to support building resilient communities through digital technologies and STI in general.

Source: Based on a contribution from the Government of the Islamic Republic of Iran.

Box 19 Turkey: Increasing the readiness of societies for disruptive innovation

One way to build resilient communities is by enhancing society's readiness for disruptive technological changes. It is known that demand from lead users is crucial to define societies' readiness for disruption. Lead users are defined as "customers that face needs ahead of the general market and who benefit significantly from finding solutions to those needs". When demand from lead users is strong, the pull towards disruptive innovation is higher and vice versa. In Turkey, the definition of research and development projects in the national smart manufacturing technology road map has facilitated the process of determining potential areas of lead users. Based on this information, policies that integrate considerations from both the supply and demand sides will provide a better chance of success for enhancing societies' readiness for disruptive innovation.

Source: Based on a contribution from the Government of Turkey.

G. INTERNATIONAL COLLABORATION

International collaboration plays a critical role in the provision of global STI that enables community-based technological solutions for resilience-building. Such collaboration generates information on cross-border natural hazards such as weather events and disease outbreaks, which feeds into community and national-level services. For example, the World Meteorological Organization provides online information on tropical cyclones, heavy rain and snow, thunderstorms, gales and fog.[81] The United Nations Platform for Space-based Information for Disaster Management and Emergency Response makes available space-based scientific knowledge and technology for disaster management. In the area of health, the Pandemic Influenza Preparedness Framework coordinated by the World Health Organization allows for the rapid collection and analysis of influenza viruses, increasing national preparedness capacities and equitable access to antivirals and vaccines (**box 20**).

Box 20 Pandemic Influenza Preparedness Framework

The Pandemic Influenza Preparedness Framework is a partnership between the major players in the international response to pandemic influenza. The Framework has the following two objectives: improve the sharing of influenza viruses with the potential to cause a human pandemic; and establish more predictable, efficient and equitable access to the benefits that result from the sharing of such viruses, notably vaccines and antiviral medicines. The World Health Organization coordinates the sharing of influenza viruses through an international network of public health laboratories called the Global Influenza Surveillance and Response System. This network has been collecting and monitoring influenza viruses for more than 65 years.

Vaccination is a critically important intervention to prevent pandemic viruses. Following the re-emergence of A(H5N1) in 2004, it became clear to member States that a formal arrangement was needed to increase the access of developing countries to vaccines and other pandemic influenza response supplies and to improve and strengthen the sharing of influenza viruses with human pandemic potential for global monitoring, risk assessment and the development of safe and effective pandemic influenza vaccines. The Framework was unanimously adopted by the 194 member States of the World Health Organization during the World Health Assembly in 2011. More than 140 national influenza centres in the Global Influenza Surveillance and Response System collaborate continuously to collect and test specimens for influenza viruses, both seasonal viruses and influenza viruses with human pandemic potential.

Under the Framework, countries are expected to support their national influenza centres and ensure that they share influenza viruses with human pandemic potential in a rapid, systematic and timely manner with a small number of specialized laboratories within the Global Influenza Surveillance and Response System. These specialized laboratories perform molecular testing and other advanced analyses. They use the viruses to develop candidate vaccine viruses, testing kits and different types of reagents. Laboratory, clinical and epidemiological data are used to assess the risk that influenza viruses with human pandemic potential might evolve into pandemic viruses. An Internet-based tool called the influenza virus traceability mechanism is used to track the sharing of influenza viruses with human pandemic potential and other materials (collectively known as pandemic influenza preparedness biological materials to external entities), such as the manufacturers of vaccines. The results of molecular analyses and tests on influenza viruses with human pandemic potential are recorded in the mechanism. The mechanism helps increase the transparency of the work of the Global Influenza Surveillance and Response System with influenza viruses with human pandemic potential; a key principle of the Framework.

The Framework contributes to resilient communities in two ways, namely, by increasing the equity of access by all countries in need to pandemic response supplies such as antivirals and vaccines and by strengthening preparedness capacities in countries where they are weak. In 2014–2017, the World Health Organization invested $64 million of the partnership contribution to support 72 countries to improve their pandemic influenza preparedness capacities. Some examples of success include the following: 35 countries are now able to detect unusual respiratory disease events, representing a five-fold increase from seven countries in 2014; 34 countries have functioning inpatient influenza surveillance, doubled from 16 countries in 2014; 29 countries have a human-animal interagency coordination mechanism, four times more than in 2014; eight countries have estimated the influenza disease burden, of which three have published their findings in peer-reviewed journals; and the world's first vaccine deployment simulation portal has been launched. Ultimately, improving public health systems and capacities provides for more resilient communities.

Source: Based on a contribution from the World Health Organization.

Collaborative global research platforms advance the development of scientific tools that contribute to resilience. For example, the Food and Drug Administration of the United States, through its "Precision FDA" programme, connects experts from around the world and provides tools, data and a framework for running community-based challenges, such as the biothreat challenge focused on early detection during pathogen outbreaks

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[81] See https://severe.worldweather.wmo.int/.

(e.g. outbreaks of Ebola virus disease in West Africa).[82] Collaborative platforms are also effective in engaging Governments and practitioners. For example, the 100 Resilient Cities platform provides member cities with financial and logistical guidance and curated resilience-building tools and services. Another example is the Digital Humanitarian Network, which leverages digital volunteers in support of humanitarian response. National and international initiatives have been established to support the participation of the general public in scientific processes, mainly by initiating and supporting citizen science projects and performing research on citizen science, including the Citizen Science Association, the Australian Citizen Science Association and the European Citizen Science Association. In 2017, the Citizen Science Global Partnership, a network of networks, was launched to promote and advance citizen science.

Development cooperation can build capacity in new technologies with the potential to increase the resilience of communities (**box 21**). Statistics on official development assistance do not track the amount of bilateral assistance specifically targeting resilience but the amount of official development assistance for economic infrastructure, which contributes to the provision of goods and services and ultimately the resilience of economies and communities, increased from $8 billion in 2000 to $22 billion in 2016 (UNCTAD calculations, based on data from the Organization for Economic Cooperation and Development). International collaboration also takes the form of supporting intergovernmental processes for disaster risk reduction and resilience-building (**box 22**).

Box 21 Germany: Development cooperation in technology to build resilient communities

The Federal Ministry for Economic Cooperation and Development launched the Green People's Energy for Africa initiative to support partner countries in developing decentralized energy structures based on renewable energy technologies in rural regions with the help of municipalities, cooperatives and private-sector investments. The project helps build the local capacity of municipalities in Africa to provide affordable, reliable and sustainable energy. The initiative supports the independence and resilience of communities. Decentralized renewable energy fosters resilience to shocks in fuel markets and provides energy security. The initiative will establish energy partnerships between African and German communities and support countries in Africa in creating a suitable framework for people's energy cooperatives, thereby promoting the rapid deployment of off-grid solutions for energy access.

Source: Based on a contribution from the Government of Germany.

Box 22 Japan: International cooperation in disaster risk reduction and resilience-building

Japan has experienced various disasters, including earthquakes, volcanic eruptions, floods, landslides, tsunamis and others. Through the Disaster Management Bureau of the Cabinet Office, Japan took an active role in international cooperation for disaster risk reduction at the World Conference on Natural Disaster Reduction in Yokohama, Japan, in 1994; and the World Conference on Disaster Reduction in Kobe, Japan, in 2005. The Bureau also had a key role in hosting the third United Nations World Conference on Disaster Risk Reduction in Sendai, Japan, in 2015. At the Conference, the Government of Japan advocated the importance of mainstreaming disaster risk reduction. The Cabinet Office encouraged and supported the international consortium on landslides to propose the International Strategy for Disaster Risk Reduction–International Consortium on Landslides Sendai Partnerships 2015–2025 as a voluntary commitment at the World Conference.

Source: Saya, 2017.

In the United Nations system, several agencies, such as the World Health Organization and the World Meteorological Organization, have programmes to promote STI solutions that contribute directly to building resilient communities.[83] At the regional level, regional commissions have promoted regional cooperation on STI for resilience. For example, the Economic and Social Commission for Asia and the Pacific has a programme on ICT and disaster risk reduction covering resilience-building, monitoring droughts from space, regional cooperation in space-based applications and a space and geographic information system for disaster management.[84] The drought mechanism is an example of regional cooperation, providing free, timely access to space-based data, products and services to participating countries, which also receive training and other capacity-building support. The Economic and Social Commission for Western Asia has promoted resilience-building by assisting the development of national digital transformation strategies, including addressing the links between ICT and governance and conflict prevention.[85] At the community level, members of United Nations country teams (e.g. the United Nations Development Programme, the United Nations Children's Fund and the World Food Programme) have used market-ready new technologies to implement early warning and preparedness systems; help develop national capacities to manage disaster risk; help develop vulnerability analysis and mapping; and support social protection systems.[86]

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[82] See https://precision.fda.gov/challenges/3.

[83] See https://www.who.int/risk-communication/en/ and https://www.wmo.int/pages/prog/www/DPFSERA/EmergencyResp.html.

[84] See https://www.unescap.org/our-work/ict-disaster-risk-reduction.

[85] See https://www.unescwa.org/our-work/governance-and-conflict-issues.

[86] See, for example, http://www1.wfp.org/resilience-building.

The focal point in the United Nations system for the coordination of disaster reduction is the United Nations Office for Disaster Risk Reduction. It ensures synergies among disaster reduction activities and activities in socioeconomic and humanitarian fields. It also acts as a broker, bringing together representatives from science and academia with other stakeholders, including civil society and community-based actors, through the organization of regional and global platforms for disaster risk reduction. The Office maintains Prevention Web, an online knowledge platform for disaster risk reduction, and develops products such as the Global Assessment Report through partnerships with scientific, civil society and private sector communities. The International Science and Technology Conference held by the Office in 2016 resulted in the science and technology road map to support the implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030. The road map includes expected outcomes, actions and deliverables under each of the priority actions of the Sendai Framework (**box 23**). There are also several cross-cutting actions such as capacity development, gender equity, citizen engagement, public–private partnerships and coherence or alignment with other post-2015 global agendas such as the 2030 Agenda and the United Nations Framework Convention on Climate Change which need to be linked with the actions of other stakeholders in the implementation of the Sendai Framework.

Box 23 Summary of the expected outcomes of the science and technology road map to support the implementation of the Sendai Framework for Disaster Risk Reduction 2015–2030

1. Understanding disaster risk

1.1 Assess and update the current state of data, scientific and local and indigenous knowledge and technical expertise availability on disaster risk reduction and fill the gaps with new knowledge.

1.2 Synthesize, produce and disseminate scientific evidence in a timely and accessible manner that responds to the knowledge needs of policymakers and practitioners.

1.3 Ensure that scientific data and information support are used in monitoring and reviewing progress towards disaster risk reduction and resilience-building.

1.4 Build capacity to ensure that all sectors and countries have access to, understand and can use scientific information for better-informed decision-making

2. Strengthening disaster risk governance to manage disaster risk

2.1 Support stronger involvement and use of science to inform policymaking and decision-making within and across all sectors at all levels

3. Investing in disaster risk reduction for resilience

3.1 Provide scientific evidence to enable decision-making of policy options for investment and development planning

4. Enhancing disaster preparedness for effective response, and to build back better in recovery, rehabilitation and reconstruction

4.1 Identify and respond to the needs of policymakers and decision makers at all levels for scientific data and information to strengthen preparedness, response and to build back better in recovery, rehabilitation and reconstruction to reduce losses and impacts on the most vulnerable communities and locations.

Source: United Nations Office for Disaster Risk Reduction, 2016.

H. POLICY CONSIDERATIONS

This section summarizes the key points from the study and discusses implications for national government policies.

1. SCIENCE, TECHNOLOGY AND INNOVATION FOR BUILDING RESILIENT COMMUNITIES

STI play a critical role in building community resilience. Diverse fields of science generate new knowledge to better understand the mechanisms and drivers of community resilience; new market-ready technologies create innovative opportunities for increasing economic, social and environmental resilience; and new approaches to innovation can bring together non-traditional innovation actors to pool efforts and resources towards community resilience, as follows:

- Knowledge of resilience: Governments and relevant stakeholders are encouraged to strengthen research programmes concerning root causes, mechanisms and drivers affecting the use of STI for building the resilience of communities, to better guide effective STI-enabled interventions;

- Use of scientific tools: All stakeholders should promote the use of scientific tools, including geospatial information and earth observation systems, to provide and share risk information at different scales before, during and after shocks, to increase resilience through better preparedness and strengthened capacity to cope;

- Scientific collaboration: Several fields of science contribute directly and indirectly to building resilient communities. However, this knowledge is often fragmented and there is a need to promote and implement participatory research methods and interdisciplinary and transdisciplinary scientific collaboration to increase understanding of community resilience, considering integrated disaster reduction and sustainable transformation;

- Indigenous knowledge: Traditional, local and Indigenous knowledge has been effectively used in reducing the risk of disasters and in supporting livelihoods. Harnessing such knowledge could lead to new scientific developments that contribute to building resilient communities. It is therefore important to consider and validate traditional, local and indigenous knowledge and systematically use it in scientific research focused on community resilience;

- Inclusive technologies: STI solutions for building community resilience should be inclusive, engaging the participation of the poorest and most vulnerable. It is crucial to support the participation of local communities as co-creators of related innovations, including social innovations. Governments should adopt inclusiveness in formulating STI for resilience strategies;

- Enabling technologies: To support the use of STI for building community resilience, Governments and all relevant stakeholders are encouraged to invest in enabling technology infrastructure such as ICT and electricity, with a specific emphasis on ensuring affordable access and overcoming geographical, gender-related, generational and income-related digital divides;

- Natural hazards triggering technological disasters: Given the complex nature of disasters, there is a need to promote the reduction of the risk of natural hazards triggering technological disasters. It is important to develop an analytical framework to take such risks into consideration when considering strategies for building resilient communities;

- Private sector participation: STI stakeholders should explore workable models that leverage the participation of the private sector in the innovation cycle of the creation of new products and services for community resilience;

- Linkages among stakeholders: There should be an open dialogue on resilience between science and technology sectors and policymakers, facilitating networking between them and creating and implementing a systematic framework in which considerations regarding resilience are used for planning and development based on scientific evidence. Such a dialogue should also contribute to strengthening resilience governance and accountability;

- STI Policies: Governments are encouraged to design and implement STI policies that contribute to building resilient communities, including through support for strategies and mechanisms that create an enabling environment for the mission-driven and late-stage deployment approaches that are characteristic of this innovation system;

- New approaches to innovation: Governments are encouraged to use mechanisms such as incubators, accelerators, innovation labs and marketplaces, as well as inclusive, grass-roots and social innovations to promote the creation of new products and services for community resilience;
- Policy coherence: Governments are encouraged to align STI policies with public health, disaster management and other relevant policies to make them responsive to building resilient communities;
- National platforms: Governments are encouraged to establish or strengthen existing national platforms for a more effective use of STI for resilience. This should integrate the wide range of knowledge and expertise available in the national science and technology community into national platform activities, whereby community leaders, policymakers and practitioners may indicate their specific needs regarding STI for resilience.

2. CITIZEN SCIENCE

Citizen science engages the participation of non-scientist citizens in the generation of new scientific knowledge. This approach is enabled by new technologies, including ubiquitous and low-cost sensors, together with improved methods for data storage, retrieval and processing. The active involvement of citizen scientists throughout the life cycle of an operational research or aid project can enhance local uptake, support local diagnostics and increase decision-making capacity, as follows:

- Embedding into science policies: Citizen science initiatives should be promoted, building the capacity of communities and citizens to collect, use and analyse data, through budget allocation, programme and/or project planning and execution and the dissemination of citizen science outcomes in global forums. Citizen science should be embedded in the routine way that science is conducted to support policymaking processes;
- Data privacy and sharing: All stakeholders should promote the sensible use of geographic information system data acquired as part of citizen science initiatives in developing countries and act to protect citizens' privacy. In this regard, they should also promote the establishment of platforms for the coordination and compilation of data collected in citizen science projects to be available for use in other development-related initiatives;
- Linkages with the Sustainable Development Goals: Tangible, executable linkages, programmes and projects between citizen science and the Goals should be established and addressed, including those related to building resilience, in particular in line with the priorities of vulnerable communities.

3. INTERNATIONAL COOPERATION

- Capacity development: The international community needs to continue investing in STI for resilience and citizen science. It needs to strengthen human and social capital, building upon what communities have already achieved as a baseline and sustaining the work of community leaders, managers and champions on the ground. as well as ensuring the documentation of such community-level work so that it may be published and available in the public domain to facilitate community learning in other settings;
- Inclusive participation: The international community should adopt policies and strategies that encourage women and youth to participate in innovative approaches towards resilience, including through citizen science;
- International partnerships: The international community should facilitate developing countries to realize mutual bilateral and multilateral, North–South and South–South partnerships that help build capacity for STI for resilience, including through citizen science;
- Experience-sharing: There is a need to actively promote various types of effective STI for resilient communities and the sharing of practical and advanced STI-based resilience experiences, cases and successful paradigms through various forms of international collaboration and exchange activities. Such platforms could be utilized at both the national and international levels and by the international community during national and transnational crises;
- Action needed: The United Nations and Governments at all levels should fully support the development of STI solutions for building resilience, including through reducing the risk of disasters and promoting sustainable transformation to advance the implementation of the Sendai Framework and the 2030 Agenda for Sustainable Development and the achievement of the Sustainable Development Goals.

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Layout and Printing at United Nations, Geneva – 1921275 **(E)** – February 2020 – 380 – **UNCTAD/DTL/STICT/2019/11**