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on

The role of science, technology and innovation in building resilient communities, including through the contribution of citizen science

Advance Unedited Draft

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Prepared by the UNCTAD Secretariat[i]

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Contents

List of Boxes

List of Tables

List of Figures

I. Introduction

At its twentieth-first session, held in Geneva, Switzerland in May 2018, the Commission on Science and Technology for Development selected "The role of science, technology and innovation in building resilient communities, including through the contribution of citizen science" as one of its two priority themes for the 2018–2019 intersessional period.

To contribute to a better understanding of this theme and to assist the Commission in its deliberations at its twenty-second session, the Commission secretariat prepared this issues paper based on relevant literature and country case studies contributed by Commission members.

This issues paper identifies, analyses and presents for discussion key issues concerning the role of science, technology and innovation (STI) in building resilient communities. The paper is structured as follows. Section II sets the stage by discussing the impact of shocks on sustainable development, the concept of resilience, and the elements of strategies for building the resilience of communities. Section III illustrates new technological solutions for building resilient communities, their characteristics and skills requirements. Section IV discusses the role of science for community resilience, focusing on the use of traditional, local and indigenous knowledge, and on new approaches to engage the participation of citizens in science for building resilience. Section V discusses mission-driven innovations systems for building resilient communities, and new approaches to innovation that are enabled by digital technologies. Section VI presents and discusses some key technical, social, market and policy challenges in using STI for resilient communities. Section VII presents some considerations regarding STI policies. Section VIII discusses the international collaboration for the provision of global and national solutions on STI for resilience. Section IX presents policy considerations for the Member States, the CSTD, and other relevant stakeholders. Section X lists questions for discussions to further the dialogue related to the role of science, technology and innovation in building resilient communities, including through the contribution of citizen science.

II. Context

A. Impact of shocks on sustainable development

People around the world are continuously affected by shocks from different sources, including economic crises, health emergencies, social conflicts, war, and natural disasters. These shocks have severe impact on the progress of communities and countries towards sustainable development.

For example, in 2009, the global financial and economic crisis of 2008-2009 resulted in a worldwide recession, with a reduction of 0.6 per cent in the world's gross domestic product (GDP). The crisis affected developing economies through the collapse of international trade,[2] which, coupled with the food and fuel crises, slowed down the progress towards the Millennium Development Goals in the aftermath.[3] In the period from 2009 to 2017, two other broad-based economic shocks – the European sovereign debt crisis of 2010-2012 and the global commodity price realignments of 2014-2016 – have resulted in economic slowdown, affecting jobs and the capacity of many governments to provide better access to public services, including health and education, adding to the hardship of vulnerable

[2] For a discussion on the impact of the crisis, see UNCTAD and Hochschule fur Technik und Witschaft Berlin (2010). *The financial and economic crisis of 2008-2009 and developing countries*. UNCTAD/GDS/MDP/2010/1. Sales No. E.11.II.D.11. New York and Geneva, December 2010.

[3] United Nations (2009). *The Millennium Development Goals Report 2009*. New York, 2009.

groups almost everywhere. Recent improvements in economic activity, with expected global GDP growth at 3.0 per cent in 2018 and 2019, has not been shared evenly across countries and regions.[4]

While economic crises have broad effects on livelihoods, shocks such as diseases, accidents, and war claim the highest toll in terms of human lives. In 2016, noncommunicable diseases resulted in over 41 million deaths (see Table 1), most of them caused by cardiovascular disease, cancer, chronic respiratory disease, and diabetes. In 2018, outbreaks of diseases affected thousands of people and triggered emergency preparations and response to deal with diseases such as Chikungunya (in Kenya and Sudan), Cholera (in Algeria, Cameroon, Democratic Republic of the Congo, Mozambique, Niger, Somalia, United Republic of Tanzania, and Zimbabwe), and Ebola (in the Democratic Republic of the Congo).[5] In 2013, road traffic crashes killed 1.25 million people and injured up to 50 million worldwide. In 2016, 180 thousand people were killed in wars and conflicts, not including deaths resulting from indirect effects such as the spread of diseases, poor nutrition and the collapse of health services.[6]

Table 1. Global impact of hazards, selected indicators

Impact	Type of hazard	2017	Annual average (2008-2017)
Deaths	Air pollution-related diseases	7 million[3]	NA
	Noncommunicable diseases	41 million[3]	NA
	Road traffic crashes	1.25 million[4]	NA
	Wars and conflicts	180,000[3]	NA
	Natural disasters[1]	11,843	72,390
	Industrial accidents[2]	4,615	6,802
Affected (Injured, homeless or requiring assistance)	Natural disasters	95.9 million	199.1 million
	Industrial accidents	21,497	65,894
Displaced (number of people)	Natural disasters	18.8 million	24.6 million
	Conflicts	11.8 million	7 million
Economic costs (USD)	Natural disasters	$ 337.5 billion	$ 152.8 billion[5]
	Industrial accidents	$ 5 million	$ 8 billion[5]

Sources: UNCTAD calculations based on data from EM-DAT: The Emergency Events Database - Université catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium; IDMC (2018). GRID 2018: Global report on internal displacement. Internal Displacement Monitoring Centre. Norwegian Refugee Council; and WHO (2018). World Health Statistics 2018: Monitoring health for the SDGs, sustainable development goals. Geneva: World Health Organization; 2018.
Notes: 1) Disasters by natural hazards include earthquakes, mass movement, volcanic activity, extreme temperature, fog, storm, flood, landslide, wave action, drought, glacial lake outburst, wildfire, epidemic, insect infestation, animal accident, impact of asteroids, meteoroids and comets; 2) Industrial accident includes chemical spill, collapse, explosion, fire, gas leak, poisoning, radiation, oils spill, and transport accident such as air, road, rail and water, and miscellaneous accident (collapse, explosion, fire, other); 3) Estimate for 2016; 4) Estimates for 2013; 5) Average damage from 2007 to 2016 in 2016 prices.

[4] United Nations (2018). *World Economic Situation and Prospects 2018*. United Nations, New York, 2018. Sales No. E.18.II.C.2.
[5] For more information, see https://www.who.int/csr/don/archive/year/2018/en/
[6] WHO (2018). *World Health Statistics 2018: Monitoring health for the SDGs, sustainable development goals*. World Health Organization; 2018. Geneva.

Environmental risk factors, such as air, water and soil pollution, and chemical exposures, also contribute to more than 100 diseases affecting people worldwide. In 2016, over 7 million people died from air pollution-related diseases, including stroke and heart disease, respiratory illness and cancers.[7] In 2012, 12.6 million people died as a result of living or working in an unhealthy environment – nearly one in four of total global deaths.[8] In 2018, around 93 per cent of the world's children under the age of 15 years old (1.8 billion children) were breathing air that was so polluted that their health and development were at serious risk.[9]

These environmental risk factors are expected to intensify with the threat of climate change, which increases the risk of rising sea levels, floods, heat waves, droughts, desertification, water shortages and the spread of tropical and vector-borne diseases. If its impact is not addressed, by 2030, there could be 325 million people living in poverty and exposed to the full range of natural hazards and climate extremes, particularly in sub-Saharan Africa and South Asia.[10]

Disasters caused by natural hazards result in thousands of deaths and affect millions of people every year. In 2017, they killed over 11 thousand people and affected more than 95.9 million. Disasters from industrial and transport accidents have caused over 4.6 thousand deaths and affected over 21.4 thousand people worldwide. Disasters also result in high economic costs (in 2017, it caused an estimate of USD 337.5 billion), which affects economic growth and poverty reduction.[11] In 2017, conflicts and disasters displaced 30.6 million people across 143 countries and territories.[12]

Moreover, communities across the world are becoming ever more at risk of complex threats driven by the increasing global economic interdependence. Natural disasters are a common cause for supply chain disruptions, affecting business and decreasing the productive capacity of firms in the affected regions, often resulting in widespread damage and systematic losses felt simultaneously in multiple locations. Another complex threat is the risk of natural hazards triggering technological disasters (NATECH), such as the Fukushima Daiichi nuclear disaster initiated primarily by the tsunami following the Tōhoku earthquake on 11 March 2011.

Technology itself can be a source of shocks. For example, while recent rapid technological change is considered central to help progress towards sustainable development,[13] it has also revived concerns about technological unemployment and the increase in inequality, and it has contributed to a shift in types of employment in many countries, with job polarization and wage and income growth concentrated at the upper end of the income distribution.[14] New developments in Artificial

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[7] Ibid.

[8] Prüss-Ustün, A., Wolf, J., Corvalán, C., Bos, R. and Neira, M. (2016). *Preventing diseases through healthy environments: A global assessment of the burden of disease from environmental risks*. World Health Organization 2016. Geneva.

[9] For more information, see https://www.who.int/news-room/detail/29-10-2018-more-than-90-of-the-world%E2%80%99s-children-breathe-toxic-air-every-day

[10] ODI (2013). *The geography of poverty, disasters and climate extremes in 2030*. Overseas Development Institute, October 2013.

[11] UNCTAD calculations based on data from EM-DAT: The Emergency Events Database - Université catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium.

[12] IDMC (2018). *GRID 2018: Global report on internal displacement*. Internal Displacement Monitoring Centre. Norwegian Refugee Council.

[13] UNCTAD (2018). *Technology and Innovation Report 2018: Harnessing Frontier Technologies for Sustainable Development*. UNCTAD/TIR/2018.

[14] United Nations (2018). *Financing for Development: Progress and Prospects 2018*. Report of the Inter-agency Task Force on Financing for Development. New York, 2018. Sales no. E.18.I.5.

Intelligence (AI) could affect jobs not only in routinized occupations in developed countries but also in developing countries through trade and changes in patterns of specialization.

In summary, social, economic and environmental shocks can derail and even set back the progress towards sustainable development. Building resilience of people, communities and countries is, therefore, critical for the achievement of the 2030 Agenda for Sustainable Development and the Sustainable Development Goals (SDGs).[15]

B. Resilience, risk reduction and sustainable development

Conceptually, resilience is usually associated with the idea of recovering from shocks. Some of the definitions of resilience emphasize stability and the return to an original state. In this case, important elements for the assessment of resilience are the threshold of disturbance that the system can sustain and still return to an original state, and the time that it takes. Other definitions emphasize the transformation and adaptation of a system to changing circumstances.[16] A common element of the different definitions of resilience is the idea that recovery in a changing environment requires the capacity to withstand, absorb and adapt to shocks or shifting conditions (see Box 1).[17]

Building resilience is a common thread across global development frameworks such as the 2030 Agenda for Sustainable Development, the Addis Ababa Action Agenda,[18] the Sendai Framework for Disaster Risk Reduction 2015-2030,[19] the Paris Agreement,[20] the Agenda for Humanity,[21] and the New Urban Agenda.[22] For example, the SDG 11 explicitly aims at increasing resilience of cities and human settlements, and several SDGs' targets are directly related to resilience, such as target 1.5 on building the resilience of the poor to reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters (see Table 2).

The several definitions of resilience and its importance in different global frameworks reflect the fact that resilience is a multidimensional outcome of development. The higher the level of development of people, communities, institutions, economic sectors or governments, the higher the potential resilience that they have against shocks. The term "potential" is used because the level of resilience is only revealed after the shock, and sometimes only in the long-term. Strategies for building resilience, therefore, could be like those to promote development, in its several dimensions, but with an emphasis on proactively preventing or minimizing the negative effects of shocks.

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[15] A/RES/70/1.

[16] Folke, C. (2006). Resilience: The emergence of a perspective for social-ecological systems analyses. *Global Environmental Change*, 16, 253-267.

[17] ESCAP (2012). *Building resilience to natural disasters and major economic crises*. ESCAP Theme Study.

[18] A/RES/69/313.

[19] A/RES/69/283.

[20] FCCC/CP/2015/10/Add.1.

[21] A/70/709.

[22] A/RES/71/256.

Box 1. Examples of definitions of resilience

"A measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (*Holling C.S, 1973. Resilience and Stability of ecological systems. International Institute for Applied Systems Analysis. Laxemburg, Austria*)

"The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization and the capacity to adapt to stress and change." (*IPCC, 2007. Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*)

"[T]he existence, development and engagement of community resources by community members [who] intentionally develop personal and collective capacity to respond to and influence change, to sustain and renew the community, and to develop new trajectories for the communities' future." (*Magis, K., 2010 Community resilience: an indicator of social sustainability. Society & Natural Resources 23 (5) pp. 401–416*)

"Disaster Resilience is the ability of countries, communities and households to manage change, by maintaining or transforming living standards in the face of shocks or stresses - such as earthquakes, drought or violent conflict – without compromising their long-term prospects." (*Department for International Development, 2011. Defining Disaster Resilience: A DFID Approach Paper)*

"The ability of people, households, communities, countries, and systems to mitigate, adapt to and recover from shocks and stresses in a manner that reduces chronic vulnerability and facilitates inclusive growth." (*USAID, 2012. Building Resilience to Recurrent Crisis, USAID Policy and Program Guidance.*)

"The working definition of a resilient country (…) is (…) one that has the capability to 1) adapt to changing contexts, 2) withstand sudden shocks and 3) recover to a desired equilibrium, either the previous one or a new one, while preserving the continuity of its operations." (*World Economic Forum, 2013. Global Risks 2013 - Eighth Edition. REF: 301211*)

"The capacity of countries to withstand, adapt to, and recover from natural disasters and major economic crises – so that their people can continue to lead the kind of life they value." (*ESCAP, 2012. Building resilience to natural disasters and major economic crises. ESCAP Theme Study*)

"The ability of a system, community or society exposed to hazards to resist, absorb, accommodate, adapt to, transform and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions through risk management." (*A/71/644*)

"The ability to deal with change and continue to develop." (*Stockholm Resilience Centre: https://www.stockholmresilience.org/research/resilience-dictionary.html*)

"Resilience is the capacity of a social-ecological system to absorb or withstand perturbations and other stressors such that the system remains within the same regime, essentially maintaining its structure and functions. It describes the degree to which the system is capable of self-organization, learning and adaptation." (*Resilience Alliance: https://www.resalliance.org/resilience*)

Source: Based on ESCAP (2012). Building resilience to natural disasters and major economic crises. ESCAP Theme Study.

Table 2. Targets related to risk resilience in the Sustainable Development Goals

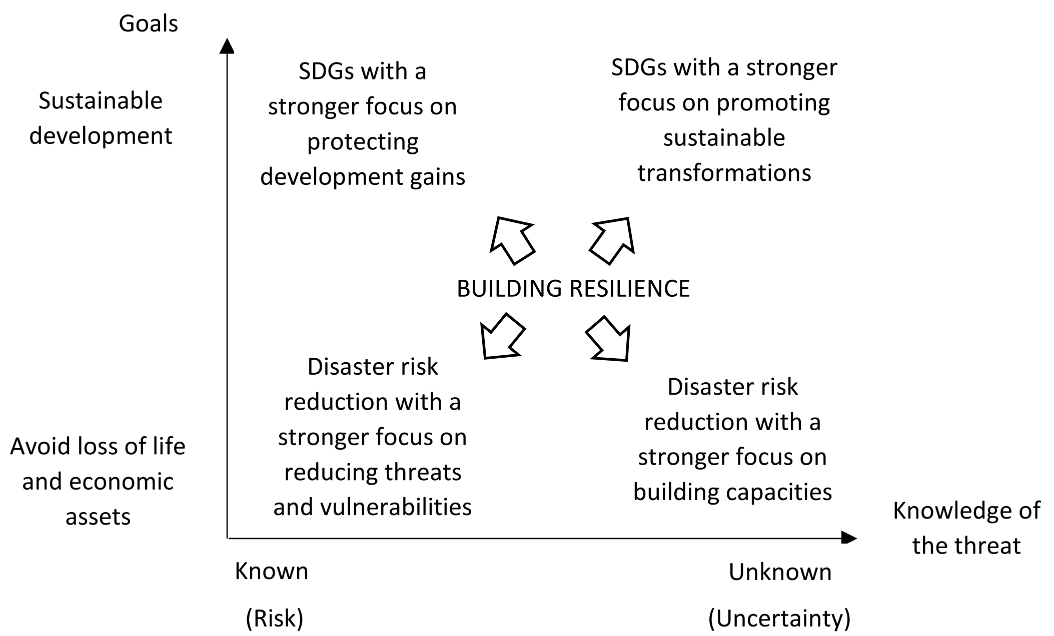
Sustainable Development Goals	Targets related to risk resilience
Goal 1: Ending poverty in all its forms everywhere	Target 1.5: By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters
Goal 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture	Target 2.4: By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality
Goal 3: Ensure healthy lives and promote well-being for all at all ages	Target 3d: Strengthen the capacity of all countries, in particular developing countries, for early warning, risk reduction and management of national and global health risks
Goal 4: Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all	Target 4a: Build and upgrade education facilities that are child, disability and gender sensitive and provide safe, non-violent, inclusive and effective learning environments for all
Goal 9: Build resilient infrastructure, promote sustainable industrialization and foster innovation	Target 9.1: Develop quality, reliable, sustainable and resilient infrastructure, including regional and transborder infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all
	Target 9.a: Facilitate sustainable and resilient infrastructure development in developing countries through enhanced financial, technological and technical support to African countries, least developed countries, landlocked developing countries and small island developing States
Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable	Target 11.5: By 2030, significantly reduce the number of deaths and the number of people affected and substantially decrease the direct economic losses relative to global gross domestic product caused by disasters, including water-related disasters, with a focus on protecting the poor and people in vulnerable situations
	Target 11.b: By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and develop and implement, in line with the Sendai Framework for Disaster Risk Reduction 2015-2030, holistic disaster risk management at all levels
	Target 11.c: Support least developed countries, including through financial and technical assistance, in building sustainable and resilient buildings utilizing local materials
Goal 13: Take urgent action to combat climate change and its impacts	Target 13.1: Strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries
Goal 15: Protect, restore and promote sustainable use of terrestrial ecosystems	Target 15.3: By 2030, combat desertification, restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land degradation-neutral world

Source: Based on E/ESCAP/CDR(5)/1.

In a simplification for illustrative purposes, the concept of building resilience could be considered in a continuum between disaster risk reduction and sustainable development (Figure 1). When focusing on protecting lives, livelihoods and assets, the strategies for building resilience largely overlap with those for reducing the risk of disasters. These strategies focus on reducing threats and vulnerabilities and increasing capacities to cope with and recover from disasters. If dealing with known threats, such as recurrent natural hazards (e.g. floods, tropical cyclones, and earthquakes), the interventions to build resilience usually involve mitigation, preparedness, response and recovery from shocks, with a stronger focus on prevention (i.e. reducing threats and vulnerabilities). When the threats are difficult to foresee, as in the case of complex shocks driven by the effects of natural hazards and global economic and trade interlinkages, the idea of reducing threats and vulnerabilities becomes less relevant given that these are also unknown or hard to foresee. In these cases, strategies for building resilience are more aligned to those of disaster risk reduction focusing on building capacities to cope, adapt and recover from shocks.

When resilience is considered in the context of sustainable development, there is a stronger focus on a conscious and deliberated directionality of the adaptation to changing circumstances. This direction is towards the sustainable development goals in its three dimensions: economic, social and environment. Therefore, building resilience would entail strategies that largely overlap with those to promote the progress towards the SDGs. When dealing with known risks, these strategies would also apply disaster risk reduction interventions to protect development gains. When dealing with uncertainty and unknown shocks, the strategies for building resilience would focus strongly on promoting sustainable transformations.

Figure 1. Resilience and the continuum between disaster risk reduction and sustainable development



Source: UNCTAD.

This paper 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 (CEB) (see Box 2), as part of an analytical framework for the United Nations System on risk and resilience (see Box 3):[23]

Resilience is *"[t]he 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."*

This definition represents a broadening of the concept of resilience from its origins in the study of ecosystems and earlier conceptions that focused on absorptive, adaptive and transformative capacities in response to natural hazard events, with less emphasis on proactively preventing or resisting them.

Box 2. United Nations harmonized definitions

Resilience: 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. (UNDG/IASC 2015)

Capacity: The combination of all the strengths, attributes and resources available within an organization, community or society to manage and reduce risks and strengthen resilience. (based on OEWG 2016)

Exposure: The situation of people, infrastructure, housing, production capacities and other tangible human assets located in hazard-prone areas. (OEWG 2016)

Hazard: A process, phenomenon or human activity, including violent conflict and human rights violations, that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation. (based on OEWG 2016)

Prevention: Activities and measures to avoid existing and new risks and the actual impacts of hazards. (based on OEWG 2016)

Risk: The potential loss of life, injury or destroyed or damaged assets which could occur to a system, society or a community in a specific period of time, determined probabilistically as a function of hazard, exposure, vulnerability and capacity (i.e., Risk = Threat x Vulnerability/Capacity) (based on OEWG 2016)

Threat: A combination of hazard and exposure encompassing both the events that could occur and the people or assets potentially affected by them. (based on INFORM 2017)

Vulnerability: The conditions determined by physical, social, economic and environmental factors or processes which increase the susceptibility of an individual, a community, assets or systems to the impacts of hazards. (OEWG 2016)

Source: CEB/2017/6, Annex III. INFORM 2017: INFORM Global Model: Interpreting and Applying: guidance note; OEWG 2016: Report of the Open-Ended Intergovernmental Expert Working Group on Indicators and Terminology Relating to Disaster Risk Reduction; UNDG/IASC 2015: United Nations Development Group/Inter-Agency Standing Committee Principles on Fostering Resilience.

[23] CEB/2017/6.

Box 3. Analytical framework for the United Nations System on risk and resilience

To better understand the relationship between risk of threats and resilience in the context of sustainable development, the High-level Committee on Programmes of the United Nations System Chief Executives Board for Coordination (CEB) approved, in its thirty-fourth session in Geneva in September 2017, an analytical framework for the United Nations System on risk and resilience. The framework is based on: (a) systems thinking to identify and understand the complex interlinkages among risks and other sustainable development issues at multiple levels; (b) 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 (c) 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 the progress.

Source: CEB/2017/6.

C. Building resilient communities

A community is a useful unit for considering resilience because it puts at the centre of the analysis the people, who can act within their sphere of influence, while at the same time considering the social interrelations, economic activities, assets and infrastructure that are at their reach.[24] The exact boundaries of communities are flexible. When considering small villages in remote areas, the community is more easily circumscribed geographically, economically and socially, as compared with people in a neighbourhood in a large city. Nevertheless, the focus on community resilience contrasts with a focus on the resilience of cities, regions or nations, and draws the attention to issues such as last-mile infrastructure, local governance, first responders, early warning, grassroots solutions and traditional, local and indigenous knowledge.

Considering the three dimensions of sustainable development, a resilient community is organized socially in a way that sufficiently empowers their people - women and men, girls and boys - to be better able to absorb and adapt to shocks (Table 3). It has the capacity to assess hazards and vulnerabilities, plan for contingency, integrate risk reduction into local development plans, promoting learning and capacity to replicate good practices.[25] It should be connected internally and externally, bringing together areas and sectors that had previously been disconnected,[26] linking with local government agencies and non-governmental organizations. It should also be organized, strengthening the sense of agency of individuals and organizations, increasing social cohesion, [27] involving women, the youth and vulnerable groups in decision making, increasing trust within the community, reducing the risk of conflicts, and having the ability to create local solutions in response to local problems.[28]

[24] IFRC (2012). *Characteristics of a safe and resilient community*. 1224200 E 05/2012. Geneva.

[25] For example, see Kafle, S. K. (2012). Measuring disaster-resilient communities: A case study of coastal communities in Indonesia. *Journal of Business Continuity & Emergency Planning*, [s. l.], v. 5, n. 4, p. 316–326.

[26] For example, see Salvia, R., Quaranta, G. (2017). Place-based rural development and resilience: A lesson from a small community. *Sustainability* 2017, 9, 889.

[27] Berno, T. (2017). Social enterprise, sustainability and community in post-earthquake Christchurch: Exploring the role of local food systems in building resilience. *Journal of Enterprising Communities: People and Places in the Global Economy*, Vol. 11 Issue: 1, pp.149-165.

[28] Barr, S., Devine-Wright, P. (2012) Resilient communities: sustainabilities in transition. *Local Environment*, 17:5, 525-532.

Table 3. Elements of a resilient community

5 Ps of the 2030 Agenda		3 Dimensions of Sustainable Development	Components of a resilient community	SDGs
Partnership	People	Social: sufficiently empower their people to be better able to absorb and adapt to shocks	Knowledgeable and healthy; ability to assess, manage and monitor its risks; It can learn new skills and build on past experiences.	SDGs 1, 2, 3, 4, 10
			Connected. It has relationships with external actors who provide a wider supportive environment, and supply goods and services when needed.	SDGs 16, 17
	Peace		Organized. It has the capacity to identify problems, establish priorities and act. Involve women, the youth and vulnerable groups in decision making.	SDGs 5, 16
	Prosperity	Economy: has an economy that can adapt to changed circumstances and self-organize to continue functioning	Increasing economic opportunity and diversification. Financial inclusion.	SDGs 8, 9
			Resilient infrastructure and safe critical infrastructure.	SDGs 6, 7, 9, 11
	Planet	Environment: Able to carry out all its activities without harming the environment	Manage natural resources. Sustainable infrastructure and services, and sustainable production and consumption.	SDGs 12, 13, 14, 15

Source: Based on IFRC (2012). *Characteristics of a safe and resilient community*. 1224200 E 05/2012. Geneva.

A resilient community has a diversified economy that can adapt to changed circumstances and self-organize to continue functioning at times of crises.[29] Communities with more diversified economies are more resilient because they have more productive capacities (i.e. capital-embodied technologies, productive resources, entrepreneurial capabilities and production linkages), which could be used as building blocks and recombined in innovative ways to continue to produce goods and services during and after crises. This includes diversification of agricultural production in rural communities,[30] as well as income and livelihood diversification at the household level.[31] A critical element for economic resilience is the existence of resilient infrastructure, including safe critical infrastructure such as hospitals, electricity, transport and communications. A resilient community also carries out all its activities without harming the environment, while reconnecting with natural life supporting systems.[32]

[29] For example, see Berkes, F., Ross, H. (2013). Community Resilience: Toward an Integrated Approach. *Society and Natural Resources*, 2013. 26(1), pp. 5-20.

[30] For example, see Amuzu, J., Jallow, B.P., Kabo-Bah, A.T., Yaffa, S. (2018). The climate change vulnerability and risk management matrix for the coastal zone of The Gambia. *Hydrology*, 2018, 5(1),14.

[31] Armitage, D., Charles, A., Berkes, F. (2017). *Governing the coastal commons: Communities, resilience and transformation*. pp. 1-271.

[32] Ziervogel, G., Cowen, A., Ziniades, J. (2016). Moving from adaptive to transformative capacity: building foundations for inclusive, thriving, and regenerative urban settlements. *Sustainability* 2016, 8, 955.

A critical consideration in building the resilience of communities, particularly regarding interventions carried out by external actors, is that communities that are affected should be fully engaged in interventions, projects and strategies from the beginning (See Box 4). Through promoting engagement and participation, they would be empowered to act quickly and to find solutions for their own problems.[33]

Box 4. Engaging communities from the beginning of a health emergency

One of the major lessons learnt from the Ebola response in West Africa (2014-2015) was that often communities were involved too little, too late. Communities need to be engaged from the very beginning of a health emergency and included in all aspects of the response. Particular attention must be given to involving groups within communities that are often not visible or marginalized and not represented by institutions such as youth groups. It is also important to give communities the power to decide how best to be involved. One such example is to implement focus group discussions to empower groups and communities to influence decision processes (e.g., when policy interventions are needed, or concrete public health decisions are to be made). It is equally important to provide the necessary resources (tools, knowledge, finances) and build community capacity outside of emergencies. Community engagement also means building democratic institutions in a community. Best practice examples were those that involved communities and helped them deal with trauma, stigma and other psychosocial side-effects of the disaster such as “community healing dialogues” in highly affected areas.

Source: Based on a contribution from WHO.

However, promoting community engagement is not necessarily an easy task.[34] Some communities are harder to engage,[35] particularly those that are underserved, which shows some limits in the capacity of their members to embrace community empowerment policies.[36] Possible barriers to community engagement are related to notions of identity, power, and agency,[37] as well as the weak practice of participatory governance by the local government.[38] Some of the possible solutions are to promote co-design of interventions,[39] involving direct participation in the development and maintenance of

[33] For example, see UNICEF/UNDP/World Bank/WHO Special Programme for Research and Training in Tropical Diseases. Community-directed interventions for major health problems in Africa: a multi-country study: final report. Geneva: TDR; 2008.

[34] For example, see Steiner, A.A., Farmer, J. (2018). Engage, participate, empower: Modelling power transfer in disadvantaged rural communities. *Environment and Planning C: Politics and Space*, 2018, 36(1), pp. 118-138.

[35] For example, see Markantoni, M., Steiner, A., Meador, J.E., Farmer, J. (2018). Do community empowerment and enabling state policies work in practice? Insights from a community development intervention in rural Scotland. *Geoforum*, 2018, 97, pp. 142-154.

[36] For example, see Steiner, A.A., Farmer, J. (2018). Engage, participate, empower: Modelling power transfer in disadvantaged rural communities. *Environment and Planning C: Politics and Space*, 2018, 36(1), pp. 118-138.

[37] Arakawa, S., Sachdeva, S., Shandas, V. (2018). Environmental stewardship: Pathways to community cohesion and cultivating meaningful engagement. In Dhiman, S. and Marques, J. (Eds). *Handbook of Engaged Sustainability*, 1-2, pp. 273-295.

[38] For example, see Patel, S., Sliuzas, R., Georgiadou, Y. (2016). The practice of participatory governance by the local government is even weaker, leading to ineffective or closed participatory spaces. *Environment and Urbanization ASIA* 7(1), pp. 1-21.

[39] Markantoni, M., Steiner, A., Meador, J.E., Farmer, J. (2018). Do community empowerment and enabling state policies work in practice? Insights from a community development intervention in rural Scotland. *Geoforum*, 2018, 97, pp. 142-154.

technological solutions for resilience,[40] and using creativity and arts to spark engagement of among community members,[41] including through cultural practices and school-based programmes.[42]

D. The role of science, technology and innovation for resilience: a framework for analysis

A broad range of science, technology and innovation (STI) solutions contribute directly and indirectly for resilience, reflecting the fundamental role of STI for development as recognized in the major global frameworks (see Box 5). Regarding the sustainable dimensions discussed in the previous section, STI has a critical role to play in building resilient communities. First, technologies, particularly digital technologies, have played a vital role in empowering and giving voice to people, including those most vulnerable. They are used for extending access to education and health, for assessing and monitoring health and environmental risks, to connect people within and outside the communities, and for the operationalization of early warning systems. Second, innovation is the 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 to protect them from failure and avoid a negative impact on the communities. Third, new technologies and innovative products and services hold the promise of decoupling economic development from environmental degradation, promoting environmental sustainability.

To facilitate a focused discussion by the Member States on the role of science, technology and innovation in building resilient communities, this paper covers on the following key aspects:

- Technology: Rapid technological development is opening new pathways for resilience building efforts at community-level.[43] While recognizing the critical importance of traditional technologies in this context, this paper 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 these technologies for community resilience.
- Science: 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 transmission of diseases, to advances in weather prediction models that increase the reliability of early warning systems. Acknowledging this fact, this paper focuses on three aspects of the role of science in building resilient communities: the status of the scientific research that seeks to understand better the resilience of communities, the use of indigenous knowledge, and recent ways to engage citizens in contributing and participating in scientific research for resilience.
- Innovation: 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,

[40] Arevian, A.C., O'Hora, J., Jones, F., et al. (2018). Participatory technology development to enhance community resilience. *Ethnicity and Disease*, 2018, 28, pp. 493-502.
[41] van der Vaart, G., van Hoven, B., Huigen, P.P.P. (2018). Creative and arts-based research methods in academic research. Lessons from a participatory research project in the Netherlands. *Forum Qualitative Sozialforschung*, 2018, 19(2),19.
[42] Somasundaram, D., Sivayokan, S. (2013). Rebuilding community resilience in a post-war context: Developing insight and recommendations - A qualitative study in Northern Sri Lanka. *International Journal of Mental Health Systems*, 2013, 7(1),3.
[43] For example, see Belliveaua, J. (2016). Humanitarian access and technology: opportunities and applications. *Procedia Engineering* 159 (2016) 300–306.

most innovations that increase people's capabilities (e.g. food and nutrition, health, education, housing, transport and communication), as well as those related to enabling technologies such as Information and Communication Technologies (ICTs), could be considered as contributing to community resilience. This paper focuses on a subset of these innovations, those that explicitly address the resilience of communities. The paper discusses the state of innovation activity, the systems of innovation that characterizes this innovation process, and new approaches for innovation towards resilience, which are enabled by digital technologies.

Box 5. Role of STI in major development frameworks

The Agenda 2030 for Sustainable Development launched a Technology Facilitation Mechanism for STI for SDGs. The Agenda lists technology as a key means for implementation in SDG17, explicitly refers to technology in 14 targets, and in another 34 targets it relates to issues discussed in technological terms.[44]

The Sendai Framework calls for enhancing "access to and support for innovation and technology" and "long-term, multi-hazard and solution-driven research and development in disaster risk management".[45]

Article 10 of the Paris Agreement deals with the "long-term vision of technology development and transfer" to improve resilience to climate change.[46]

The Agenda for Humanity[47] "encourage[s] business leaders to utilize leverage, knowledge and technology to contribute to sustainable solutions that bring stability and dignity to people's lives." It calls for bilateral and South-South cooperation in providing expertise, knowledge transfer and technology; and encourages a strong focus on innovation, specialization and consolidation in the humanitarian sector.

The New Urban Agenda[48] includes commitments for encouraging urban-rural interactions and connectivity by strengthening technology and communications networks and infrastructure, including new technology that enables shared mobility services, making efforts to leverage innovations in technology and to produce a better living environment.

Source: Based on E/ESCAP/CDR(5)/1.

[44] United Nations (2016). *Global Sustainable Development Report 2016*. Department of Economic and Social Affairs, New York, July.
[45] See General Assembly resolution 69/283, annex II, paras 25 (g) and (i).
[46] See FCCC/CP/2015/10/Add.1, annex, articles 10 (1) and 10 (4).
[47] A/70/709.
[48] A/RES/71/256.

III. Technology for building the resilience of communities

A. Building social resilience

1. Reducing vulnerabilities and building capacities to cope

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 ICTs, including space technologies such as satellite communications, facilitate access to healthcare services through telemedicine or eHealth,[49] allowing physicians to access, monitor and diagnose patients remotely.

In the area of mental health, web-based therapy and telemedicine have applications such as in the treatment for posttraumatic stress disorders,[50] in improving students' depression, anxiety, and stress outcomes,[51] in generating a positive psychology intervention for cardiac patients,[52] in reducing anxiety and depression symptoms in mildly depressed adults,[53] as well as in the treatment of substance abuse and eating disorders.[54] Telemedicine has also been successfully used to inform, engage and communicate with patients with chronic diseases; empowering them with ICT tools for monitoring, training and self-management of the diseases. Telemedicine can potentially improve outcomes in treatments such as cancer care,[55] chronic kidney disease,[56] and diabetes care.[57] 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 to unhealthy diet and other unhealthy behavior.[58] The improved outcomes through telemedicine related to anxiety, depression and chronic diseases reduce the vulnerability of patients, thus increasing resilience.

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[49] For example, see Graschew, G., Roelofs, T.A., Rakowsky, S., Schlag, P.M. (2008). *Satellite-based networks for u-health & u-learning*. *European Space Agency*, (Special Publication) ESA SP (660 SP).

[50] For example, see Foa, E.B., Gillihan, S.J., Bryant, R.A. (2013). Challenges and successes in dissemination of evidence-based treatments for posttraumatic stress: Lessons learned from prolonged exposure therapy for PTSD. *Psychological Science in the Public Interest*, 2013. Supplement, 14(2), pp. 65-111.

[51] For example, see Davies, E.B., Morriss, R., Glazebrook, C. (2014). Computer-delivered and web-based interventions to improve depression, anxiety, and psychological well-being of university students: *A systematic review and meta-analysis. Journal of Medical Internet Research*, 2014, 16(5), pp. e130

[52] For example, see Huffman, J.C., Mastromauro, C.A., Boehm, J.K., et al. (2011). Development of a positive psychology intervention for patients with acute cardiovascular disease. *Heart International*, 2011, 6(2), pp. 47-54.

[53] For example, see Bolier, L., Haverman, M., Kramer, J., et al. (2013). An internet-Based intervention to promote mental fitness for mildly depressed adults: Randomized controlled trial. *Journal of Medical Internet Research*, 2013, 15(9),e200.

[54] For example, see Siemer, C.P., Fogel, J., Van Voorhees, B.W. (2011). Telemental health and web-based applications in children and adolescents. *Child and Adolescent Psychiatric Clinics of North America* 20(1), pp. 135-153.

[55] For example, see Agboola, S.O., Ju, W., Elfiky, A., Kvedar, J.C., Jethwani, K. (2015). The effect of technology-based interventions on pain, depression, and quality of life in patients with cancer: A systematic review of randomized controlled trials. *Journal of Medical Internet Research* 17(3), e65.

[56] For example, see Diamantidis, C.J., Becker, S. (2014). Health information technology (IT) to improve the care of patients with chronic kidney disease. *BMC Nephrology*, 2004, 15(1),7 (CKD).

[57] For example, see Baig, A.A., Wilkes, A.E., Davis, A.M., et al. (2010). Review paper: The use of quality improvement and health information technology approaches to improve diabetes outcomes in African American and Hispanic patients. *Medical Care Research and Review* 67(5), pp. 163S-197S.

[58] For example, see Mayén, A.L., Marques-Vidal, P., Paccaud, F., Bovet, P., Stringhini, S. (2014). Socioeconomic determinants of dietary patterns in low- and middle-income countries: a systematic review. *The American Journal of Clinical Nutrition*, Volume 100, Issue 6, 1 December 2014, Pages 1520–1531.

Telemedicine could be an important tool in bridging the gap in the access to health services between urban and rural communities (see Box 6). Satellite technology has been used to improve care for patients in rural areas,[59] not only in developed regions but also in developing countries in Asia and sub-Saharan Africa.[60] For spacefaring developing nations with large geographical coverage like China and India, satellite technology is a suitable technology to reach underserved communities.[61] It allows for flexible methods of broadband communication with high reliability and cost-effectiveness of connections. It is also a tested technology with decades of use for telemedicine.[62] Satellite solutions also enable other services such as eLearning and eGovernment, coordination of emergency responses and humanitarian assistance using data and satellite communications, and biodiversity conservation.[63]

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

While many forward strides had been made over recent years in the Egyptian health ecosystem, in terms of overall mortality rates, vaccination and immunization efforts, and expansion and improvement of medical infrastructure, some challenges remained unresolved. One major challenge is the unequal distribution of resources between cities and rural governorates as the specialized medical services are in the country's major cities. To receive medical services a patient usually must travel to either the capital of the governorate he or she is in, or travel to the capital city of the country, incurring high costs of transportation, and rendering it quite a difficult journey for severely ill patients. Women are more severely affected than men because traditional customs prevent them from travelling unaccompanied. Offering remote telemedicine diagnostic services is a major asset to such communities. The process of successful implementation of telemedicine initiatives has influenced the policy implications for the future expansion of a workable model into all of Egypt's marginalized regions, through the creation of strategic partnerships with major health institutions.

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

Telemedicine requires a reliable, wireless communication link between the devices monitoring patients and the clinicians.[64] Rapid advances in wireless communications, networking technologies, and medical technologies, have facilitated the development of emerging mobile healthcare services, including for emergency healthcare (e-emergency). Developments in wireless video systems for reliable communications could significantly affect the delivery of healthcare,[65] given the availability of bandwidth in the next-generation of wireless communications networks, and new wireless video-

[59] For example, see Turnin, M.-C., Schirr-Bonnans, S., Chauchard, M.-C., et al. (2017). DIABSAT Telemedicine Itinerant Screening of Chronic Complications of Diabetes Using a Satellite. *Telemedicine and e-Health* 23(5), pp. 397-403.

[60] For example, see Martín-de-Mercado, G., Horsch, A., Parentela, G., Mancini, P., Ginati, A. (2011). *Satellite-enhanced telemedicine and eHealth for sub-Saharan Africa: A development opportunity*. 62nd International Astronautical Congress 2011, IAC 2011 5, pp. 4320-4327.

[61] For example, see Rajashekhar, S.L., Ayyangar, G. (2012). Satellite technology to reach the unreached (India-A case study). *Proceedings - 2012 IEEE Global Humanitarian Technology Conference*, GHTC 2012 6387045, pp. 186-191.

[62] For example, see Murakami, H., Shimizu, K., Yamamoto, K., et al. (1994). Telemedicine Using Mobile Satellite Communication. *IEEE Transactions on Biomedical Engineering* 41(5), pp. 488-497.

[63] For example, see Acevedo, R., Varela, F., Orihuela, N. (2010). The role of Venesat-1 satellite in promoting development in Venezuela and Latin America. *Space Policy* 26(3), pp. 189-193.

[64] For example, see Kacimi, R., Pech, P. (2013). Satellite and wireless links issues in healthcare monitoring. Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering, LNICST 123 LNICST, pp. 49-64.

[65] For example, see Herscovici, N., Christodoulou, C., Kyriacou, E., et al. (2007). m-health e-emergency systems: Current status and future directions. *IEEE Antennas and Propagation Magazine*, 2007, 49(1), pp. 216-231.

compression standards.[66] This technology has been used in applications such as medical video streaming,[67] and the wireless transmission of medical ultrasound video over mobile networks.[68]

Mobile phone diffusion across all societal segments has also increased the reach of public health services to remote communities through using mobile phones to exchange text, photos and videos between local health workers and specialized clinics (For example, see Box 7). Mobile phones 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, improve their capacity to directly influence the delivery of public services and hold local government accountable.[69]

Box 7. River Moms: improving maternal and child health in rural communities of the Peruvian Amazon

Through the Project "Mamás del río: mejorando la salud materna e infantil en comunidades rurales de la Amazonía Peruana" (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 of pregnant women to a medical boat and health centers that attend these communities. This allows prenatal visits to be prepared and pregnant women to receive timely attention.

The solution uses an application capable of collecting numerical data, text, GPS, photos, videos and audio, through Android devices and send that information to an online server to which the boat and the health centers have access. The project worked with communities that had a telephone signal and the political commitment to mobilize midwives, community agents and health promoters to training.

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

At the same time, some challenges need to be addressed to upscale these ICT solutions. For example, while the Internet could build a trusted community that helps in the management of mental health of young people, unsupervised online forums could attract adults who may take advantage of vulnerable adolescents.[70] Patients may also be unwilling to use telemedicine, despite the advantages of reduced travel and convenience, due to concerns that the remote care is of inferior quality when compared to visits to clinics and the in-person care by health workers.[71] In some situations, telemedicine may not result in the expected increase in performance. For example, in a study to determine whether telemedicine influenced the accuracy of triage in disaster response, in which paramedics used the mobile device Google Glass to communicate with an off-site physician disaster expert, the procedure

[66] Panayides, A., Pattichis, M.S., Pattichis, C.S., Pitsillides, A. (2011). A tutorial for emerging wireless medical video transmission systems. *IEEE Antennas and Propagation Magazine* 53(2),5949369, pp. 202-213.
[67] For example, see Martini, M.G., Istepanian, R.S.H., Mazzotti, M., Philip, N.Y. (2010). Robust multilayer control for enhanced wireless telemedical video streaming. *IEEE Transactions on Mobile Computing* 9(1),4906997, pp. 5-16.
[68] For example, see Panayides, A., Antoniou, Z.C., Mylonas, Y., et al. (2013). High-resolution, low-delay, and error-resilient medical ultrasound video communication using H.264/AVC over mobile WiMAX networks. *IEEE Journal of Biomedical and Health Informatics* 17(3), pp. 619-628.
[69] For example, see Georgiadou, Y., Bana, B., Becht, R. et al. (2011). Sensors, empowerment, and accountability: A digital earth view from East Africa. *International Journal of Digital Earth* 4(4), pp. 285-304.
[70] For example, see Webb, M., Burns, J., Collin, P. (2008). Providing online support for young people with mental health difficulties: Challenges and opportunities explored. *Early Intervention in Psychiatry*, 2008, 2(2), pp. 108-113.
[71] For example, see Call, V.R.A., Erickson, L.D., Dailey, N.K., et al. (2015). Attitudes toward telemedicine in urban, rural, and highly rural communities. *Telemedicine and e-Health* 21(8), pp. 644-651.

with the support of telemedicine took more time than conventional triage and did not result in an increase in triage accuracy.[72]

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 treat infections through improved bioavailability and anti-inflammatory, antioxidant, and immunomodulatory effects.[73] Another example are microneedles, a new form of drug delivery system with applications in many fields, including vaccine delivery,[74] and that is an improvement over the conventional subcutaneous administration by bringing simplicity and scalability to drug delivery.[75] By combining with a new class of thermostable vaccines that do not require refrigeration,[76] this technology can improve the resilience of communities by facilitating the delivery of vaccines in challenging conditions of poor access to electricity.[77] Innovation in the development of new vaccines and strategies to control disease outbreaks, such as for the treatment of Ebola,[78] also contribute to increase community resilience.

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 e-learning and facilitate the access to relevant and timely knowledge and information, improving the capacity to cope to shocks. Mobile technologies can support in the process of building these capacities in innovative ways. For instance, mobile phones with video recording capabilities have been used to engage the community in producing mini-documentaries, disseminated via social media, showcasing ways that people in the community could build their own capacities to increase their sense of agency. These videos present and discuss the challenges faced by the community and possible solutions to increase social cohesion. They highlight the public services and formal and informal business available to the community to increase the awareness regarding the existing life-supporting systems.[79] Mobile apps can also support the education efforts for building capacities to prepare, cope and recover from disasters (For example, see Box 8).

Digital games are an additional technological tool for building resilience. For example, the *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 an engaging, fast-

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[72] Cicero, M.X., Walsh, B., Solad, Y., et al. (2015). Do you see what I see? Insights from using Google Glass for disaster telemedicine triage. *Prehospital and Disaster Medicine* 30(1), pp. 4-8.

[73] For example, see Bell, I.R., Schwartz, G.E., Boyer, N.N., Koithan, M., Brooks, A.J. (2013). Advances in integrative nanomedicine for improving infectious disease treatment in public health. *European Journal of Integrative Medicine* 5(2), pp. 126-140.

[74] For example, see Waghule, T., Singhvi, G., Dubey, S.K., et al. (2019). Microneedles: A smart approach and increasing potential for transdermal drug delivery system. *Biomedicine and Pharmacotherapy* 109, pp. 1249-1258.

[75] For example, see Stoeber, B., Ranamukha, S., St. Clair, R. (2018). Intradermal delivery - New technology brings simplicity & scalability to intradermal drug delivery. *Drug Development and Delivery* 18(2).

[76] For example, see Naik, S.P., Zade, J.K., Sabale, R.N., et al. (2017). Stability of heat stable, live attenuated Rotavirus vaccine (ROTASIIL®). *Vaccine* 35(22), pp. 2962-2969.

[77] E/HLPF/2017/4.

[78] For more information, see https://www.who.int/ebola/drc-2018/faq-vaccine/en/.

[79] Ziervogel, G., Cowen, A., Ziniades, J. (2016). Moving from adaptive to transformative capacity: building foundations for inclusive, thriving, and regenerative urban settlements. *Sustainability* 2016, 8, 955.

paced disaster simulation. [80] Game-like programmes have also been used in computer simulation-based training for emergency response.[81]

Box 8. Example in Austria of the use of mobile apps for capacity building on disaster prevention

In Austria, as part of the project "Young Crowd", teachers and their students and interested young people use such an app to expand their knowledge and discover the existing resources of disaster prevention in their own environment. The data they collect serves to plan further experiments and to general research in crisis prevention. The approach 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 a new awareness of security and disaster risk management issues. In addition, citizen scientists use the developed mobile app and report back their experience with it.

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

2. Assessing, monitoring and managing risk

Reducing threats entails the ability to assess and monitor risks. A way to monitor environmental risks is using sensor networks. In this regard, new developments in low-cost open-source hardware, such as the Arduino platform,[82] makes it possible to develop *ad hoc* sensors[83] that can complement existing, but often sparse, monitoring networks in developing countries.[84] An example is the project "luftdaten.info" by the OK Lab Stuttgart, in which volunteers worldwide install self-built gauges on the outside wall of their homes to generate and transmit data to updated fine dust maps.[85]

Citizens operating these sensors can also provide additional information via various devices such as smartphones. This crowdsourced information is commonly known as Volunteered Geographical Information (VGI).[86] These VGI can take the form of time-stamped and geo-located photographs,[87] social media updates,[88] or interviews and feedback to *ad hoc* hazard mitigation websites.[89] The

[80] For more information, see: https://www.koshland-science-museum.org/extreme-event/
[81] Pan, J., Su, X., Zhou, Z. (2015). An alternate reality game for facility resilience (ARGFR). *Procedia Engineering* 118 (2015) 296 – 303.
[82] Arduino is a hardware platform and online user community that manufactures 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.
[83] Rieger, C. (2016). *Demonstrating the capacity of online citizen science mapping software to communicate natural hazards and engage community participation*. PhD dissertation, University of Lethbridge, 2016.
[84] For example, see Malakar, Y. (2014). *Community-based rainfall observation for landslide monitoring in western Nepal*. In: Sassa K. et al. (eds.), Landslide Science for a Safer Geoenvironment (vol. 2). Cham, Switzerland: Springer; 2014.
[85] For more information, see: https://luftdaten.info/
[86] For example, see Mee, K., Duncan, M.J. (2015). Increasing resilience to natural hazards through crowd-sourcing in St. Vincent and the Grenadines. *British Geological Survey Open Report OR*/15/32, 54 pp; 2015.
[87] For example, see Robson, C. (2012). *Using mobile technology and social networking to crowdsource citizen science*. PhD dissertation, University of California, Berkeley; 2012.
[88] For example, see Baum, R.L., Highland, L.M., Lyttle, P.T., Fee, J.M., Martinez, E.M., Wald, L.A. (2014). *"Report-a-landslide": A website to engage the public in identifying geologic hazards*. In: Sassa K. et al. (eds.), Landslide Science for a Safer Geoenvironment (vol. 2). Cham, Switzerland: Springer; 2014.
[89] Lane, S.N., Odoni, N., Landström, C., Whatmore, S.J., Ward, N., Bradley, S. (2011). Doing flood risk science differently: An experiment in radical scientific method. *Transactions of the Institute of British Geographers*, 2011, 36(1):15–36.

combination of *in situ* sensors with VGI can improve the coverage of monitored areas significantly, supporting resilience building at a community level.[90]

Smartphones equipped with sensors (e.g. transceivers, FM and GPS receivers, cameras, accelerometers, digital compasses and microphones) can also be utilised for monitoring and scientific observation.[91] For example, the standardisation of smartphones' accelerometers, combined with advances in cloud computing, have enabled 'citizen seismologists' who feed data into earthquake early warning systems (e.g. providing measurements of shaking magnitude and location and cursory analyses of the initial seismic waves).[92]

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 will soon be affordable for more developing countries, businesses and universities, which would increase the reach of communication networks and applications that use high-resolution imagery such as for monitoring land use and for urban planning.[93]

Drones offer a low-cost approach to remote sensing. They transmit images of the Earth's surface in real time, which when combined with GPS data can be exploited to populate land-use databases as well as assessments of disasters such as flood or earthquake damage. They also have application for rapid mapping in case of emergencies; for example, when used with crowdsourcing platforms that tags live footage from aerial vehicles flown during disasters.[94]

Environment monitoring generates risk assessment maps. Digital technologies have been used to produce digital maps using crowdsourced inputs from citizens. For example, the USAID's YouthMappers,[95] an international university consortium on Mapping for Resilience to create and use open geographic data; and Community Maps,[96] a platform of the *Mapping for Change* initiative that offers a range of participatory mapping services to community groups, business and government.[97]

A critical component of community resilience is the existence of local early warning systems connected with national systems. For example, in the United States, local authorities disseminate emergency alerts received from the Federal Emergency Management Agency's (FEMA) Integrated Public Alert and Warning System (IPAWS)[98]. Mobile technology adds new possibilities for early warning. For example, in the mobile-based early warning system *Surveillance in Post Extreme Emergencies and Disasters (SPEED)*, first line health workers and volunteers use mobile phones to send reports to a central database that health authorities use to detect common health conditions in an emergency (see Box 9). [99]

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[90] For example, see Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T.C., Bastiaensen, J., et al. (2014). Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science* 2014; 2:26.

[91] For example, see McCabe M.F. et al. (2017). The future of Earth observation in hydrology, *Hydrology and Earth System Science* 2017; 21(7):3879–914.

[92] Liang, W.-T., Chen, K.H., Wu, Y.-F., Yen, E., Chang, C.-Y. (2015). Earthquake school in the cloud: Citizen seismologists in Taiwan. *Seismological Research Letters* 2015; 87(1):177–85.

[93] Buscher, M. and Brieß, K. (2014). *Analysis of regulatory challenges for small satellite developers based on the TUB small satellite database*. ITU Workshop on the efficient use of the spectrum/orbit resource, Limassol.

[94] Salisbury, E., Stein, S., Ramchurn, S. (2016). CrowdAR: a live video annotation tool for rapid mapping. *Procedia Engineering* 159 (2016) 89–93.

[95] For more information, see: https://www.youthmappers.org/

[96] For more information, see: https://communitymaps.org.uk/welcome

[97] For more information, see: http://mappingforchange.org.uk/

[98] For more information, see: https://www.fema.gov/integrated-public-alert-warning-system

[99] For more information, see: http://www.wpro.who.int/philippines/areas/emergencies_disasters/speed/en/

Box 9. Surveillance in Post Extreme Emergencies and Disasters (SPEED)

SPEED is a mobile-based early warning system to detect common health conditions in an emergency. It was developed by the Department of Health, the Philippines through the support of the Australian Agency for International Development (AusAID), the United States Agency for International Development (USAID) and the Government of Finland through the technical guidance of the World Health Organization (WHO).

A strong health information system is crucial to an effective health emergency response in order to detect trends in diseases and provision of health services. In addition to an effective information system, a well-functioning health system is essential to save lives and respond to the magnitude of people who need care. SPEED uses mobile phone 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 are sent to a central portal/ databank that can be immediately accessed by health authorities at different levels. Subsequently, SPEED has been adapted by Japan to establish J-SPEED.

SPEED has been used in several emergencies in the Philippines and there have been no significant challenges. An effective information system has to be matched with a well-functioning health system that is essential to save lives and respond to the magnitude of people who need care.

Source: Based on contribution from WHO.

3. Responding to emergencies

Emergency response requires timely two-way communication for coordination and action. Mobile technology offers new possibilities for passing on information during an emergency. For example, the use of smartphones of rescue and relief workers to form a disjoint peer-to-peer communication network during emergencies,[100] or the use of mobile wireless local area network through a series of "wearable routers" when pre-existing communication infrastructure is not available.[101] Mobile technology is also used to run interactive post-disaster surveys for damage or needs assessment using SMS.[102] An example is the Vulnerability Analysis and Mapping (mVAM) project of the World Food Programme (WFP) to collect food security data in insecure or inaccessible areas through short mobile phone surveys, using SMS, live telephone interviews and interactive voice response (IVR) 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.[103] Social media is used by local agencies in emergency management to involve community members as first line informants and as first responders.[104] It also creates shared awareness and commits citizens in new ways to increase resilience.[105] 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.

[100] Bandyopadhyaya, S., Mukherjeeb, A. (2016). Tracking user-movement in opportunistic networks to support distributed query-response during disaster management. *Procedia Engineering* 159 (2016) 82–88.
[101] Hacketta, T.M., Bilén, S. G. (2016). Implementation of a rapidly deployable, mobile communications system prototype for disadvantaged environments. *Procedia Engineering* 159 (2016) 158–166.
[102] Basu M., Bandyopadhyay, S., Ghosh, S. (2016). Post disaster situation awareness and decision support through interactive crowdsourcing. *Procedia Engineering*, 159 (2016) 167 – 173.
[103] Edwards, C. (2009). *Resilient nation*. London: Demos; 2009.
[104] Díaz, P., Carroll, J.M., Aedo, I. (2016). Coproduction as an Approach to Technology-Mediated Citizen Participation in Emergency Management. *Future Internet* 2016, 8, 41.
[105] Hokkanen, L. (2016). Harnessing social media for safety. *Injury Prevention* 2016; 22: A123.

New developments in data analytics and big data can also support emergency response. For example, during a typhoid outbreak in Uganda, the Ministry of Health used data-mapping applications to allocate medicine and mobilize health teams.[106] Data analytics and big data also make external assistance to communities more effective. An example is the Emergency Dashboard by the World Health Organization (WHO), which allows monitoring of health emergencies globally to inform action, including engaging community's resources to prevent, prepare for, respond to and recover from health emergencies (e.g., 2018 Ebola Virus Disease outbreak at the Democratic Republic of the Congo, and cholera in Zimbabwe).

During emergencies, the delivery of supplies is critical but many times impractical due to collapsed infrastructure or dangerous situations. In that context, drones could revolutionise the delivery of such supplies and replace humans in hazardous tasks. Small quadcopter drones are now being employed for an increasing number of tasks, including commercial delivery of packages and delivery of high-value items such as vaccines to rural areas in developing countries. For example, in Rwanda, the government partnered with a robotics company, Zipline, to address maternal mortality by using drones to deliver blood to medical facilities, reducing the time to procure blood from four hours to fifteen minutes.[107] Drones can also be used for regular delivery of supplies in remote areas. For instance, in Canada, residents of a remote First Nation island in northern Ontario will begin receiving goods by drone in 2019 (see Box 10).

Box 10. Canada Moose Cree First Nation to get drone deliveries

The Moose Cree First Nation has signed a C$2.5m (£1.5m) commercial deal with a drone delivery company to transport supplies, medicine, food and mail from the mainland town of Moosonee, starting in 2019. Moose Factory Island is only accessible by boat in summer, ice road in winter and helicopter at other times. The drone delivery service will begin in the spring of 2019, after a year of planning. Drones will have a 5kg (11lb) maximum payload for the roughly 10-minute journey across the Moose River, where there is no bridge connecting the island reserve from its nearest town.

The objective is to serve communities that lack infrastructure, where basic goods are very difficult to obtain or are expensive. The service is designed to be affordable and fast and has the goal also to create employment for community members. In addition to delivering supplies, the drones can also help with monitoring seasonal changes such as river break-ups in the spring.

Source: Based on BBC News: https://www.bbc.com/news/world-us-canada-46500367

B. Building economic resilience

1. Increasing economic opportunities and diversification

Resilient communities should be able to generate enough and diverse occupations to employ its people, and to better adapt to changes in employment and outputs of the 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

[106] United Nations Global Pulse (2015). Data visualisation and interactive mapping to support response to disease outbreak. Global Pulse Project Series No. 20.
[107] Rwanda Biomedical Center. http://www.rbc.gov.rw/IMG/pdf/press_release_medical_drones_deliveries.pdf; Rosen, W. J. (2017). Zipline's Ambitious Medical Drone Delivery in Africa.

manage the fluctuations in resource abundance and seasonal cycles of economic activity or resource use, particularly in rural, tourism-based, and coastal fishing communities.[108]

Science, technology and innovation are critical in this process. Diversification is ultimately the result of innovation – the introduction of a new sector in the economy. The new sectors use labour- and capital-embodied technologies in the production; these technologies do not need to be new; they could 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 3D printing could enable and support the development of innovative new sectors. For example, 3D printing allows small batch production and leads to free-form product design as well as sustainable manufacturing.[109] It also shifts the location of the production process closer to either the designer or to the final consumer. At the same time, casual 3D printing makers require considerable training in using the technology and, in many cases, are deeply dependent on print centre operators to develop their 3D printing products.[110]

Some of the new sectors could be introduced by creative workers (e.g. arts and entertainment) relocating to well-connected rural regions and using new digital technologies in cultural activities in and for their communities.[111]

Economic diversification can also be the result of innovation in labour-embodied technologies (e.g. know-how, methods, procedures, norms and regulation). For example, changes in social norms that prevent the access of women to productive resources, including restrictions to access 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.[112] In other cases, diversification of livelihoods in rural households entails the migration of the youth of the family, mostly the daughters, to work in light manufacturing (e.g. textiles, 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.[113]

2. Access to energy and communication infrastructure[114]

Access to infrastructure such as electricity and communication is critical for community development as well as for its resilience. Rural and remote areas are many times underserved due to the higher costs of extending these infrastructures. New technologies can offer an alternative solution for costly investment in infrastructure related to traditional technological paradigms. For example, rapid

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[108] For example, see Adger, W.N., Kelly, P.M., Winkels, A., Luong, Q.H., Locke, C. (2002). Migration, remittances, livelihood trajectories, and social resilience. *Ambio* 31(4), pp. 358-366; and Marschke, M.J., Berkes, F. (2006). Exploring strategies that build livelihood resilience: A case from Cambodia. *Ecology and Society* 11(1),42.

[109] For a review of the literature, see Khorram Niaki, M., Nonino, F. (2017). Additive manufacturing management: a review and future research agenda. *International Journal of Production Research* 55(5), pp. 1419-1439.

[110] For example, see Hudson, N., Alcock, C., Chilana, P.K. (2016). *Understanding newcomers to 3D printing: Motivations, workflows, and barriers of casual makers*. Conference on Human Factors in Computing Systems – Proceedings pp. 384-396.

[111] For example, see Roberts, E., Townsend, L. (2016). The Contribution of the Creative Economy to the Resilience of Rural Communities: Exploring Cultural and Digital Capital. *Sociologia Ruralis*, 56(2), pp. 197-219.

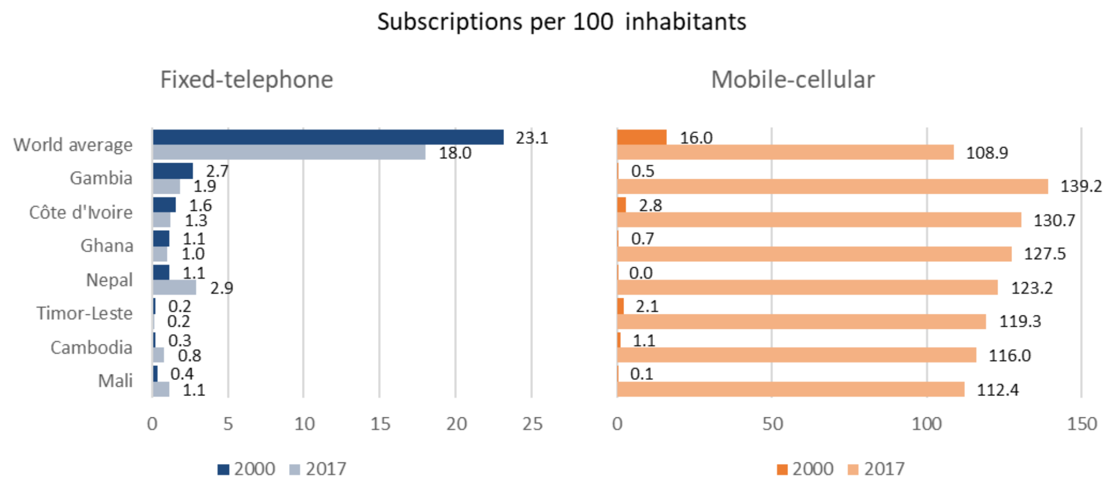
[112] For example, see Della-Giusta, M., Phillips, C. (2006). Women entrepreneurs in the Gambia: Challenges and opportunities. *Journal of International Development* 18(8), pp. 1051-1064.

[113] For example, see Bouahom, B., Douangsavanh, L., Rigg, J. (2004). Building sustainable livelihoods in Laos: Untangling farm from non-farm, progress from distress. *Geoforum* 35(5), pp. 607-619.

[114] Based on UNCTAD/PRESS/PB/2018/8 (No. 71).

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, by 2017 had reached levels of subscriptions of mobile-cellular telephones per 100 inhabitants above the global average (108.9). For example Gambia (139.2), Côte d'Ivoire (130.7), Ghana (127.5), Nepal (123.2), Timor-Leste (119.3), Cambodia (116) and Mali (112.4) (Figure 2). These are very successful examples of leapfrogging into digital telephony, and the same pattern is seen for most of the developing countries. In 2017, these countries had a penetration rate of 98.7 mobile-cellular telephone subscriptions per 100 inhabitants, while for fixed-telephones the penetration rate was 8 per 100 inhabitants.[115]

Figure 2. Example of countries that skipped fixed-telephony and moved directly to mobile communications

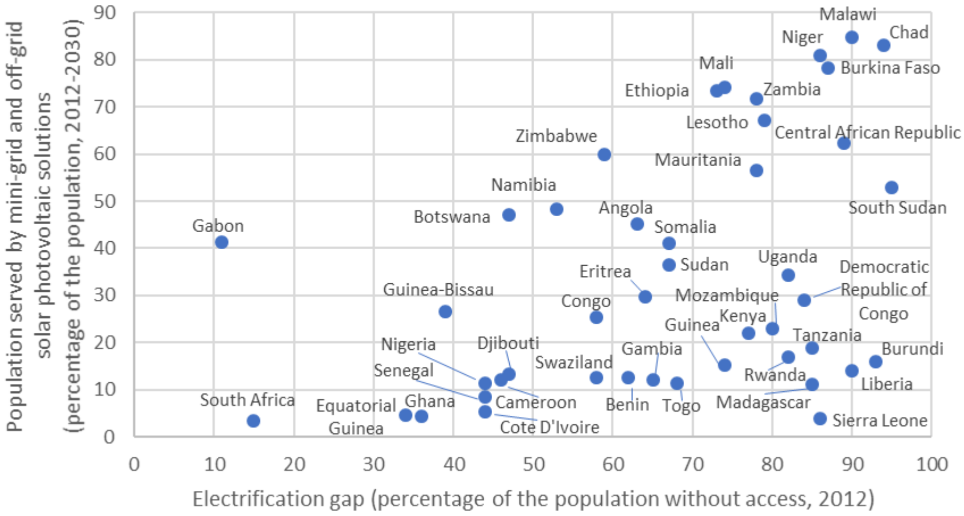


Source: UNCTAD calculations based on ITU data.
Note: Earliest data for Timor-Leste is for the year 2003, and latest data for Gambia and Mali is for the year 2016.

An example of the potential of new technologies for extending access to electricity is the development of decentralized renewable energy systems.[116] 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. These solutions could serve a large share of the population with a lower cost in Malawi (84 per cent of the population), Chad (83 per cent), 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), Central African Republic (62 per cent), Zimbabwe (60 per cent), Mauritania (57 per cent), and South Sudan (53 per cent) (Figure 3). In many cases, higher electrification gap is associated with a higher potential for leapfrogging (e.g. countries in the right part of the graph). The exceptions are due to factors such as a higher density of population close to existing or already planned national grids, which reduce the need for off-grid and mini-grid solutions.[117]

[115] UNCTAD calculations based on data from ITU.
[116] UNCTAD (2017). *The least developed countries report 2017: Transformational energy access*. United Nations publication. Sales No. E.17.II.D.6. New York and Geneva.
[117] For a discussion of the results of the model in selected countries, see Nerini, F.F. et al. (2016). A cost comparison of technology approaches for improving access to electricity services. *Energy* 95 (2016) 255-265.

Figure 3. Potential for leapfrogging in decentralized solar photovoltaic solutions



Source: UNCTAD calculations based on data from UN modelling tool "Open Source Spatial Electrification Tool (OnSSET)". Available from https://un-modelling.github.io/electrification-paths-presentation/
Note: Scenario of electrification considers 22 kWh of electricity consumption per household per year, grid electricity cost of US$ 0.1 per kWh, and the price of diesel of $0.7 per litre.

3. Financial inclusion and risk financing

A critical element of a resilient community is the capacity of their 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 to handle small transactions.

However, the rapid adoption of mobile technology has paved the way for innovative FinTech services such as the M-Pesa mobile banking system and the GrassRoots 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.[118] For example, countries in Sub-Saharan Africa have the highest percentages of adults who have a mobile money account – a regional average of 21 per cent in 2017 as compared with 4 per cent for the world. The following countries take the lead in mobile financial inclusion, with over a quarter of the poorest 40 per cent adults reporting to have personally used a mobile account service: Kenya (59 per cent), Uganda (40 per cent), Zimbabwe (40 per cent), and Gabon (37 per cent), Ghana (32 per cent), Tanzania (30 per cent), Namibia (29 per cent), Côte d'Ivoire (27 per cent), and Senegal (27 per cent).[119]

In addition to financial inclusion, there is also a need to expand the provision and access to ex-ante disaster risk financing tools such as insurance, micro-insurance and catastrophic bonds, to better protect livelihoods against different kinds of weather shocks, such as droughts and floods. Some innovations in weather insurance, such as index insurance, have benefited the poor in lower-income countries where rural and agricultural financial markets are underdeveloped. Index insurance makes payments based on an objective index, such as rainfall measures, that serve as a proxy for losses to

[118] H2 Ventures and KPMG (2017). 2017 FINTECH 100 Leading Global Fintech Innovators. Available from https://home.kpmg.com/content/dam/kpmg/qm/pdf/H2-Fintech-Innovators-2017.pdf.
[119] Global Findex database.

crops. Insurance companies use satellite imagery and computer models to create indexes as the basis of payments.[120]

Satellite data complements rainfall estimates through in situ observations. In areas in which these 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 multi-sensor soil moisture.[121] These data provide valuable inputs in index insurance, but they require operational, quality-controlled, multi-sensor datasets,[122] such as the soil moisture dataset that is generated via the Climate Change Initiative (CCI) of the European Space Agency (ESA).[123]

These technologies could also provide an 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 the crop growing season, when the results of the index already predict losses to crops, as opposed to ex-post cash transfers after harvesting. Such an early response could result in significant cost savings.[124] Weather index insurance is also used for livestock, which is also affected by droughts.[125]

Despite the clear benefits of weather index insurance for increasing the economic resilience of poorest rural communities, the uptake in developing countries, and in sub-Saharan Africa in particular, remains low, even in pilot initiatives. Some of the reasons are the poor understanding of the concept of crop insurance, inability to pay premiums, rigid enrolment criteria, low level of trust in insurance providers, and past failures of insurance models to properly estimate previous loss;[126] reflecting a failure to involve farm households at the initial conceptualization and design of pilot initiatives.[127]

C. Building environmental resilience

1. Managing natural resources

Management of natural resources is critical for resilience, given that terrestrial and marine ecosystems provide food, water, medicines, construction materials, energy, transport, shoreline stabilization, coastline protection and erosion prevention, climate regulation, oxygen production, maintenance of biodiversity, as well as recreation, aesthetic and spiritual values. These ecosystems provide a vital

[120] For a review, see Skees, J.R. (2008). Innovations in index insurance for the poor in lower income countries. *Agricultural and Resource Economics Review* 37(1), pp. 1-15.
[121] For example, see Enenkel, M., Farah, C., Hain, C., et al. (2018). What rainfall does not tell us-enhancing financial instruments with satellite-derived soil moisture and evaporative stress. *Remote Sensing* 10(11),1819.
[122] For example, see Enenkel, M., Osgood, D., Powell, B. (2017). The added value of satellite soil moisture for agricultural index insurance. *Remote Sensing of Hydrometeorological Hazards* pp. 69-84.
[123] For example, see Enenkel, M., Reimer, C., Dorigo, W., et al. (2016). Combining satellite observations to develop a global soil moisture product for near-real-time applications. *Hydrology and Earth System Sciences* 20(10), pp. 4191-4208.
[124] Guimarães Nobre, G., Davenport, F., Bischiniotis, K., et al. (2019). Financing agricultural drought risk through ex-ante cash transfers. *Science of the Total Environment* 653, pp. 523-535.
[125] For example, see Vrieling, A., Meroni, M., Shee, A., et al. (2014). Historical extension of operational NDVI products for livestock insurance in Kenya. *International Journal of Applied Earth Observation and Geoinformation* 28(1), pp. 238-251.
[126] For example, see https://www.economist.com/finance-and-economics/2018/12/15/in-africa-agricultural-insurance-often-falls-on-stony-ground.
[127] For example, see Fonta, W.M., Sanfo, S., Kedir, A.M. et al. (2018). Estimating farmers' willingness to pay for weather index-based crop insurance uptake in West Africa: Insight from a pilot initiative in Southwestern Burkina Faso. *Agricultural and Food Economics* (2018) 6: 11. https://doi.org/10.1186/s40100-018-0104-6.

basis for the livelihoods for rural and coastal communities, particularly resource-dependent communities in developing countries.

Satellite imagery and machine learning algorithms can be used for forest monitoring by tracking changes in three cover and canopy density. Artificial intelligence could also be used to cross check information regarding logging licenses with data provided by geospatial mapping systems to monitor illegal logging.[128] Drones have various applications in land and resources management, including land use dynamic monitoring, land law enforcement, land development and consolidation, real estate registration and so on.[129]

In the case of 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 for sustainable development. Marine science plays an important role in the fisheries management process, including for the adoption of conservation and management measures.[130]

Geospatial technology has unique role in efficient water use practices, and conservation of water bodies and infrastructure. Emerging technological trends include new remote sensing sensors for measuring water cycle components, ground sensors-based field instruments, cloud-based data integration and computational models, and webGIS based water information portals.[131]

The Internet of things (IoT) also offers innovative alternative solutions in several areas, including in water management and quality.[132] For example, in Bangladesh, IoT is being used to assess groundwater chemistry and protect the people in the Ganges Delta who face the threat of drinking groundwater contaminated with arsenic.[133] This reduces the need for investments in the implementation and maintenance of traditional monitoring networks.

2. Sustainable tourism

Sustainable production and consumption contribute to community resilience by helping to preserve the environment. It also opens 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. These activities usually require more knowledge than those applied in traditional sectors, and it is critical to build the capacity of the members of the community, otherwise it is not possible to meaningfully engage them (See Box 11).

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[128] Claassen, M., Coluccia, C., Demozzi, T., Drews, M.S., Slagter, L. (2018). *AI geospacial mapping systems. A transparent approach to natural resources management*. Policy Brief, Wagenningen University and Research, 2018.

[129] Xiao, L., Chen, J. (2017). Application of UAV aerial survey technology in land and resources management. *Journal of Geomatics* 42(5), pp. 96-99.

[130] A/65/69.

[131] For example, see Thakur, P.K., Aggarwal, S.P., Nikam, B.R., et al. (2018). Training, education, research and capacity building needs and future requirements in applications of geospatial technology for water resources management. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences* - ISPRS Archives 42(5), pp. 29-36.

[132] Dora, V. (2015). New to the Internet of Things? Here's what you need to know to get started. *YourStory*, 7 August.

[133] Zennaro, M., Pehrson, B. and Antoine, B. (2008). Wireless sensor networks: a great opportunity for researchers in developing countries. *Proceedings of WCITD2008 Conference*, Pretoria, South Africa.

Box 11. Kimana Ecotourism Project

The Kimana Ecotourism is a wildlife-based ecotourism project started in 1996. In this project, the people of Kimana in Kenya have sought to exploit the commercial advantage of their communal land which lies near Amboseli National Park (ANP) in southern Kenya. The Kimana Community Wildlife Sanctuary represents an examples 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 of the project is to conserve biodiversity as a source of earning foreign exchange, employment and training opportunities for the people of Kimana. In addition, the project sought 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 resource trained and hired, access improved through road network, luxury hotel constructed, and neighbouring game lodges involved in marketing and channelling tourists to the sanctuary. The local community gives game rangers feedback on wildlife movement, migration, water sources, grazing grounds etc. using cell phone technology.

However, the Kimana conservancy community lacks enough skill for meaningful engagement. Despite agreements that most of the Conservancy staff would come from Kimana only a few low-waged seasonal unskilled and manual jobs such as those of security guards, rangers, porters, casual construction workers and cleaners were made available to the local people. Most of the skilled positions such as those of managers, drivers, were filled with employees transferred or rather sourced from outside. Due to illiteracy amongst the community harnessing cell phone technology as a tool for citizen science is a problem.

Source: Based on contribution from the Government of Kenya.

Modern ICT, and geospatial ICT (Geo-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 the users (i.e. planners and managers, tourists and recreationalists) to enable them to fully benefit from the technology.[134]

Information and communication technologies are also used in viral, participative, interactive, networked and versatile marketing techniques to actively involve tourists, particularly the members of the so-called Generation Y (20-30 years old), into the culture of and activities-related to their tourism destinations.[135] In this connection, a fundamental change is the rise of social media, which facilitates search of travel-related information, reserve and book of activities, evaluate and judge tourist destination, receive travel advice and communicate one's mobility pattern. 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.[136] These have potentially innovative applications, but it is still unclear the implications for sustainable tourism.[137]

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[134] For example, see Hennig, S. (2018). Use and potential of geo-ICT for nature-based tourism and recreation in Kyrgyzstan. *International Journal of Geoinformatics* 14(1), pp. 35-42.

[135] Connecting the members of Generation Y to destination brands: A case study of the CUBIS project

[136] For example, see Dickinson, J.E., Filimonau, V., Hibbert, J.F., et al. (2017). Tourism communities and social ties: the role of online and offline tourist social networks in building social capital and sustainable practice. *Journal of Sustainable Tourism* 25(2), pp. 163-180

[137] For example, see Gössling, S. (2017). Tourism, information technologies and sustainability: an exploratory review. *Journal of Sustainable Tourism* 25(7), pp. 1024-1041.

D. Characteristics of technological solutions

Effective solutions for building resilience of communities using market-ready new technologies are multi-purpose, easy to learn and use, scalable and replicable, and are become ever more accessible.[138] Multi-purpose means that these technologies are relevant and useful before, during and after emergencies as well as in daily life. Clear examples are the mobile phone technology and smartphones, which are employed in solutions from disaster risk assessment and monitoring, to emergency response and early warning systems.

Technological solutions should be easy to learn and use. For example, this is a characteristic of social media that makes them useful for emergency response as there is no need for formal training and most people with access to a computer or smartphone can use them. In the context of sensor networks, dedicated smartphone apps have been developed to collect relevant VGI-based information in a way that is easy to use.[139] In the case of the use of drones for remote sensing, the simplification of their operation and data formats has allowed non-scientists to conduct the surveys themselves, which has been shown to stimulate interest and enthusiasm in the objectives of resilience building, when viewing real-time aerial imagery of their community often for the first time.[140]

Technological solutions for community resilience should also be scalable or replicable, and it should grow to accommodate demand. In the case of social media for emergency response, they provide scale and enable anyone to reach a large audience.

The technological solution should also be accessible, open, inclusive and increasingly affordable for consumers. This is another characteristic of the use of mobile phones for emergency response, as they have become more available at low cost. In complex technological solutions, such as early warning systems or data analytics for emergence response, the increasing accessibility of data repositories and online sharing of results make it possible to access and combine different datasets in novel, simplified, user-friendly ways. Advantages in the use of drones include the low cost of operation that allows for frequent missions, increased spatial coverage, no required installation points, and rapid deployment.[141] In the case of renewable energy technologies, international prices in renewables have fallen dramatically in recent years as investments in their development have increased. Since 2009, the cost of wind turbines has fallen by nearly a third, and that of solar photovoltaic modules by 80 per cent,[142] making both increasingly competitive with fossil fuel generation. Solar energy is now the cheapest generation technology in many parts of the world.[143] Cost reductions represent an opportunity for electrification in rural areas, especially in developing countries, through off-grid and mini-grid solutions.

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[138] IFRC, (2015). *A Vision on the Humanitarian Use of Emerging Technology for Emerging Needs*.

[139] For example, see Mee, K., Duncan, M.J. (2015). Increasing resilience to natural hazards through crowd-sourcing in St. Vincent and the Grenadines. *British Geological Survey Open Report OR*/15/32, 54 pp; 2015.

[140] Johnson, P., Ricker, B., Harrison, S. (2017). *Volunteered drone imagery: Challenges and constraints to the development of an open shared image repository*. Proceedings of the 50th Hawaii International Conference on System Sciences 2017; 1:1995–2004.

[141] Vousdoukas M.I., Pennucci G. Holman R.A., Conley D.C., (2011). A semi automatic technique for Rapid Environmental Assessment in the coastal zone using Small Unmanned Aerial Vehicles (SUAV). *Journal of Coastal Research*, SI 64 (Proceedings of the 11th International Coastal Symposium), 1755-1759. Szczecin, Poland.

[142] International Renewable Energy Agency (2016). *The Power to change: Solar and wind cost reduction potential to 2025*. International Renewable Energy Agency, June.

[143] See Jason Dorrier's interview with Ramez Naam, "Solar is now the cheapest energy there is in the sunniest parts of the World," *Singularity Hub*, 18 May 2017.

Many of the characteristics of the technological solutions described above are enabled by ICTs, and the possibilities that they bring through digitalization and connectivity. Information and communication technologies are facilitating ease of use and bringing dramatic reductions of cost resulting in the democratization of access and the emergence of new actors and forms of innovation.

E. Skills required to use, adopt, adapt and maintain the technology

People need a basic set of skills to use many of the solutions based on new technologies for building community resilience. This usually include basic education and literacy, as well as familiarity with technological devices. Basic ICT skills are required to use solutions based on smartphones and online platforms, including sensor apps, social media, and online digital maps.

Many of the technological solutions highlighted in previous sections are developed and implemented in communities in developing countries by experts or researchers from outside these communities. The sustainability and scalability of these solutions requires that people within the community can 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 may include basic computing skills, familiarity with basic algorithms, digital mapping, remote sensing and sensor network low-cost hardware and software. Maintenance of technological solutions would require, in addition to possibly basic ICT programming skills, other skills to assemble and combine technological devices, replace parts and components, and adapt of-the-shelf parts.

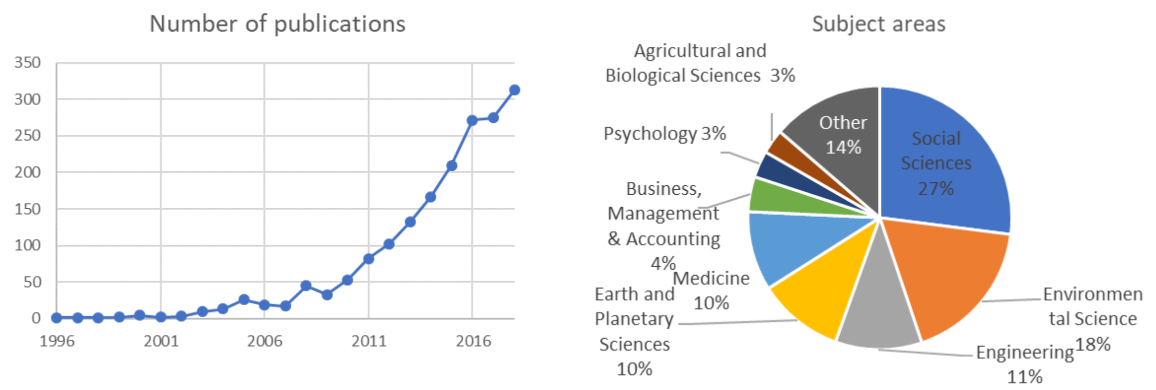
In addition to these technological capabilities, entrepreneurship skills are critical to make innovative technological solutions into products and services available in the market or provided through public services. Social entrepreneurship skills are needed to develop, fund and implement solutions with resilience of the community as the main goal.

IV. Science: Understanding resilient communities and engaging their participation

A. The science of resilient communities

Science, Technology and Innovation policies can allocate resources to conduct science in priority areas that contribute to building resilient communities. Science focusing exclusively on community resilience has been very productive. Worldwide, it has produced over 1,700 publications in the English language in the period from 1996 to 2018, representing 32 per cent of the publications in the same period related to resilience to disasters, and twice as much as the number of publications focusing on community-based disaster risk reduction.[144] The 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 that are engaged in most of this research are social sciences (27 per cent), environmental science (18 per cent), engineering (11 per cent), earth and planetary sciences (10 per cent), and medicine (10 per cent) (Figure 4).

Figure 4. Scientific publications related to community resilience, 1996-2018



Source: UNCTAD based on data from SCOPUS (accessed on 23 November 2018).

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, livelihood, and health. These clusters share many common topics particularly related to climate change and disaster risk reduction.

Research on resilient communities to the effects of climate change deals with ecosystems, natural hazards, sea level rise, coastal zone communities, and adaptive management. Some of the results of this research include the identification of the optimum combination of adaptation and mitigation measures in fast-growing cities;[145] the understanding of strengths and weaknesses of the coastal protection benefits provided by built infrastructure, natural ecosystems, and the innovative opportunities to combine the two into hybrid approaches for coastal protection;[146] and the

[144] UNCTAD calculations based on data from SCOPUS accessed on 23 November 2018.

[145] Roy, M. (2009). Planning for sustainable urbanisation in fast growing cities: Mitigation and adaptation issues addressed in Dhaka, Bangladesh. *Habitat International* 33(3), pp. 276-286.

[146] Sutton-Grier, A.E., Wowk, K., Bamford, H. (2915). Future of our coasts: The potential for natural and hybrid infrastructure to enhance the resilience of our coastal communities, economies and ecosystems. *Environmental Science and Policy* 51, pp. 137-148.

assessment of impacts and adaptation strategies to climate change in rural communities in different ecological zones.[147]

Natural hazards, particularly earthquakes and hurricanes, are also a key topic in the research that focuses on infrastructure for resilience. Research focusing on livelihoods cover 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, different impacts on men and women, and on children and adults.

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

Countries with higher scientific production related to resilient communities have funded scientific research in priority areas that are relevant to those 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,[148] and 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. bushfire, flood and drought). Some countries have separate research councils or funding agencies for social sciences, engineering and environmental science, which may increase the opportunities for funding research on community resilience based on these different vantage points, but it could also become a challenge to get funds for a more holistic research that seeks to focus on multidimensional sustainable transformations and their impact on resilience.

B. Harnessing traditional, local and indigenous knowledge

Harnessing traditional, local and indigenous knowledge could lead to new scientific developments that contribute to building resilient communities (See Box 12 for an example on controlling vector-borne diseases in Uganda).[149] Indigenous knowledge is usually acquired through interaction with the land, and with the objective to ensure survival. Therefore, this knowledge is well suited to inform science that contributes to increasing the resilience of communities in face of well-known natural hazards (e.g. floods and droughts) and in relation to their livelihoods (e.g. agriculture, animal husbandry and wildlife management). Harnessing traditional knowledge also contributes to sustaining communities'

[147] Dumenu, W.K., Obeng, E.A. (2016). Climate change and rural communities in Ghana: Social vulnerability, impacts, adaptations and policy implications. *Environmental Science and Policy*, 55, pp.208-217

[148] Australian Research Council (2018), Corporate Plan 2018-2019.

[149] For example, see Hiwasaki, L., Luna, E., Syamsidik, Shaw, R. (2014). *Local & indigenous knowledge for community resilience: Hydro-meteorological disaster risk reduction and climate change adaptation in coastal and small island communities*. Jakarta, UNESCO, 60 pp.

traditional values and in strengthening their identity, [150] while also promoting engagement of women and vulnerable groups,[151] which are important elements in building resilience.

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 China Traditional Chinese Medicine Patents Database,[152] Traditional Knowledge Digital Library (India),[153] Korean Traditional Knowledge Portal,[154] and GENESYS Gateway to Generic Resources.[155]

In some countries, scientific funding bodies have incentivized the use of indigenous knowledge in science. For example, in South Africa, Indigenous Knowledge Systems (IKS) has been a cross-cutting theme of the National Research Foundations' 10-Year Innovation Plan, including with a focus on climate change.[156] In Canada, Polar Knowledge Canada (POLAR), 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.[157]

Box 12. Harnessing traditional knowledge to control vector-borne diseases in Uganda

In Uganda, the indigenous knowledge that Phytolacca dodecandra, a locally abundant wild plant, had successfully been used to control animal and human disease, 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 like mosquitoes. It was inspired by earlier work at the Addis Ababa University to control bilharzia in Ethiopian communities. The project tested the plant for its effectiveness and subsequently developed the insecticide Snailtox used for the containment of snails that cause bilharzia in humans and liver flukes in livestock.

Source: Contribution from the Government of Uganda.

C. 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 improving data provision in data-scarce regions. [158] Citizen science can also serve to educate and empower communities and stakeholders that might otherwise be bypassed by more traditional processes of knowledge generation.

[150] Laurence, K., Megha, S., Rob, W., Stéphane, D., Colette, I. (2009). Community resilience: models, metaphors and measures. *Journal of Aboriginal Health*, Nov 2009, Vol.5(1), pp.62-117.
[151] Islam M.R., Ingham V., Hicks J., Manock I. (2017). The Changing Role of Women in Resilience, Recovery and Economic Development at the Intersection of Recurrent Disaster: A Case Study from Sirajgang, Bangladesh. *Journal of Asian and African Studies*, 52-1, 50-67.
[152] For a description, see, for example, Liu, Y., and Sun, Y. (2004). China traditional Chinese Medicine (TCM) Patent Database. *World Patent Information* Volume 26, Issue 1, March 2004, Pages 91-96.
[153] For more information, see: http://www.tkdl.res.in/tkdl/langdefault/common/Home.asp?GL=Eng
[154] For more information, see: http://www.koreantk.com/
[155] For more information, see: https://www.genesys-pgr.org/
[156] For more information, see: https://www.nrf.ac.za/division/funding/indigenous-knowledge-systems-iks-2019
[157] For more information, see: https://www.canada.ca/en/polar-knowledge/
[158] For example, see Mueller, M., Tippins, D., Bryan, L. (2012). The future of citizen science. *Democracy and Education* 2012; 20(1):1–12.

Such approach has been adopted in risk management for some time: bottom-up, community-led projects, which would nowadays be classified as citizen science, were recognised as hugely beneficial to capacity building as early as the 1980s.[159] This approach is not restricted to disaster risk reduction. There are projects such as the NASA's Zika Education and Prevention mapping project to enlist thousands of students to collect data on mosquitoes to improve tracking and control of Zika;[160] the Global Mosquito Alert Consortium, an initiative to leverage networks of scientists and volunteers for the global surveillance and control of mosquito species known to carry the following diseases (e.g Zika, yellow fever, chikungunya, dengue, malaria, and the West Nile Virus);[161] and the Earth Challenge 2020 that seeks to engage millions of people and aggregate and collect more than one billion data points on air and water quality, biodiversity, and human health (See Box 13 for other examples of citizen science projects).[162]

Box 13. Examples of citizen science projects

The **Agroclimate Impact Reporter (AIR)** 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 the data collected through its citizen science network. The information in these maps enables 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. (www.agr.gc.ca/air)

CyberTracker leverages the expertise of Kalahari bushmen to understand the impact of infectious diseases on wildlife populations like gorillas, chimpanzees, and antelopes. The bushmen can neither read nor write, but the trackers are able to select images and transmit sightings by GPS. This program helps scientists track the patterns of these animals and, in turn, give a "voice" to the bushmen and their unique knowledge. (https://www.cybertracker.org/)

IceWatch volunteers contribute to a scientific understanding of climate change by helping to record and analyze when ice forms and thaws on bodies of water. They provide critical data to cover gaps in the current monitoring network. It allows people of all ages to participate in discovering how and why the environment is changing. IceWatch is part of the NatureWatch suite of Canada's national volunteer monitoring programs designed to help identify ecological changes that may be affecting the environment. (https://www.naturewatch.ca/icewatch/)

The **National Map Corps** is an online, crowd-sourced mapping project of the U.S. Geological Survey that allows volunteers to verify data, keep the 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 data on boundaries, elevation, geographic names, hydrography, land cover, structures, and transportation, from a variety of sources, on a single platform. (https://nationalmap.gov/TheNationalMapCorps/)

SISS-Geo, of FIOCURZ from Brazil, uses mobile phones to transmit geo-referenced records informed by the users, to generate alert models of occurrences of diseases in the wild, especially those with the potential of human involvement, and models of prediction of ecological risk of disease emergence. The system provides a fast and efficient flow of information between sectors of the

[159] For example, see Paul, J.D., Buytaert, W., Allen, S., Ballesteros-Canovas, J.A., Bhusal, J., Cieslik K., et al. (2018). Citizen science for hydrological risk reduction and resilience building. *Wiley Interdisciplinary Reviews: Water* 2018; 5: e1262.

[160] For more information, see: https://www.globe.gov/web/globe-mosquito-project

[161] For more information, see: https://www.wilsoncenter.org/global-mosquito-alert; Tyson, E., Bowser, A., Palmer, J., Kapan, D., Bartumeus, F., Martin, B., Pauwels, E.. (2018). *Global Mosquito Alert: Building citizen science capacity for surveillance and control of disease-vector mosquitoes*. Wilson Center.

[162] For more information, see: https://www.earthday.org/campaigns/earthchallenge2020/

government and society, through citizen science, and it is integrated with geo-referenced governmental platforms. (https://www.biodiversidade.ciss.fiocruz.br/)

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 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. (https://toolkit.climate.gov/case-studies/where-do-we-need-shade-mapping-urban-heat-islands-richmond-virginia)

The **YouthMappers** is a local-level field-mapping USAID project to support development by leveraging a global network of universities 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, environment, resource management, and others. (https://www.youthmappers.org/)

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

1. Types of citizen science

Citizen science could involve data collection, interpretation, analysis, and dissemination of results (Figure 5).[163] It differs from more general stakeholder engagement by the active involvement of citizen volunteers throughout the life-cycle of the project, requiring motivational aspects, such as improving living standards, the quality and provision of local education, or fostering a sense of national pride.[164] Historically, citizen science was often applied on environmental data collection by volunteers.[165] Given that most community-based responses to hazards take a preventative approach,[166] or are based on real-time observation and mitigation,[167] in many projects, the role of local stakeholders is strictly limited to information gathering. These "citizen sensors" are less involved in the aims and formulation of the project, but still can provide good quality data in data-scarce regions (see Box 14).[168]

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[163] For example, see Lakeman-Fraser, P., Gosling, L., Moffat, A. J., West, S. E., Fradera, R., Davies, L., et al. (2016). To have your citizen science cake and eat it? Delivering research and outreach through Open Air Laboratories (OPAL). *BMC Ecology* 2016; 16(S1):16.

[164] Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T.C., Bastiaensen, J., et al. (2014). Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science* 2014; 2:26.

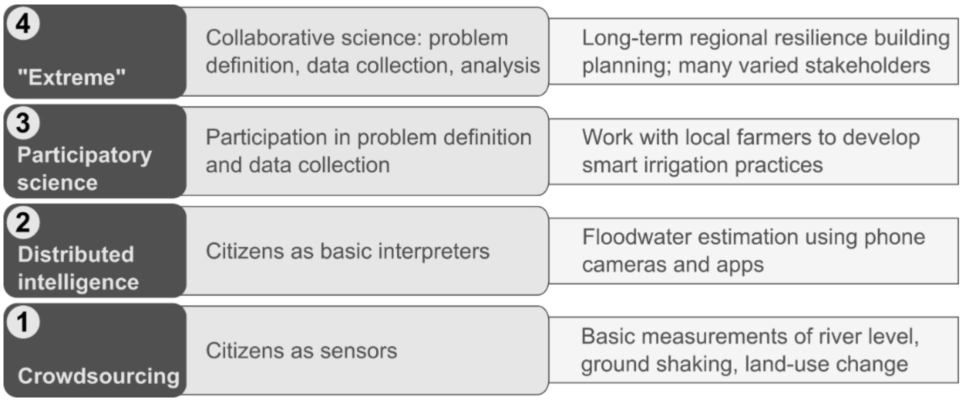
[165] For example, see Huddart, J.E.A., Thompson, M.S.A., Woodward, G., Brooks, S.J. (2016). Citizen science: From detecting pollution to evaluating ecological restoration. *Wiley Interdisciplinary Reviews: Water* 2016; 3(3):287–300.

[166] For example, see Rieger, C. (2016). *Demonstrating the capacity of online citizen science mapping software to communicate natural hazards and engage community participation*. PhD dissertation, University of Lethbridge, 2016.

[167] For example, see Johnson, P., Ricker, B., Harrison, S. (2017). *Volunteered drone imagery: Challenges and constraints to the development of an open shared image repository*. Proceedings of the 50th Hawaii International Conference on System Sciences 2017; 1:1995–2004.

[168] Robson, C. (2012). *Using mobile technology and social networking to crowdsource citizen science*. PhD dissertation, University of California, Berkeley; 2012.

Figure 5. Levels of participation in citizen science



Source: Based on Haklay, M. (2012). Citizen science and volunteered geographic information – overview and typology of participation. In: Sui D.Z., Elwood S. and Goodchild M.F. (eds.), Volunteered Geographic Information, Public Participation, and Crowdsourced Production of Geographic Knowledge. Berlin: Springer; 2012.

Box 14. A crowdsourced Approach for Hydrological Monitoring in western Kenya

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 Kenyan basin. It has also assessed whether crowdsourcing is a suitable method to overcome data scarcity. The methodology involved installation of water gauges equipped with signboards explaining the monitoring process to passers-by. Results were sent via a cellphone 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 ten measurements. Comparison of crowdsourced data with data from automatic gauging station revealed high data quality. The driving factors that kept participants involved included giving them feedback to prevent raising unrealistic expectations associated with monitoring, management plans or rewards, using available simple cell phone technology and reimbursing costs.

Source: Contribution from the Government of Kenya.

However, the recent tendency is to involve volunteers in all intellectual aspects of the science, rather than to capitalise on them as a low-cost workforce.[169] Within this perspective, it is the citizens who define the problem at hand, and then collect relevant information (e.g. observations of streamflow, air quality, ground shaking, flood damage, and so on). This *extreme citizen science*, or collaborative learning,[170] typically involves spending extended periods of time understanding the needs and concerns of a range of local stakeholders (See Box 15 for examples of citizen participation in citizen science projects in Canada).

[169] For example, see Buytaert, W., Dewulf, A., De Bièvre, B., Clark, J., Hannah, D.M. (2016). Citizen science for water resources management: Toward polycentric monitoring and governance? *Journal of Water Resources Planning and Management*, 2016;142(2):01816002.

[170] Haklay, M. (2012). *Citizen science and volunteered geographic information – overview and typology of participation.* In: Sui D.Z., Elwood S. and Goodchild M.F. (eds.), Volunteered Geographic Information, Public Participation, and Crowdsourced Production of Geographic Knowledge. Berlin: Springer; 2012.

Box 15. Examples of types of participation of citizens in citizen science in Canada

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 apps. For example, the Bumble Bee Watch by 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.

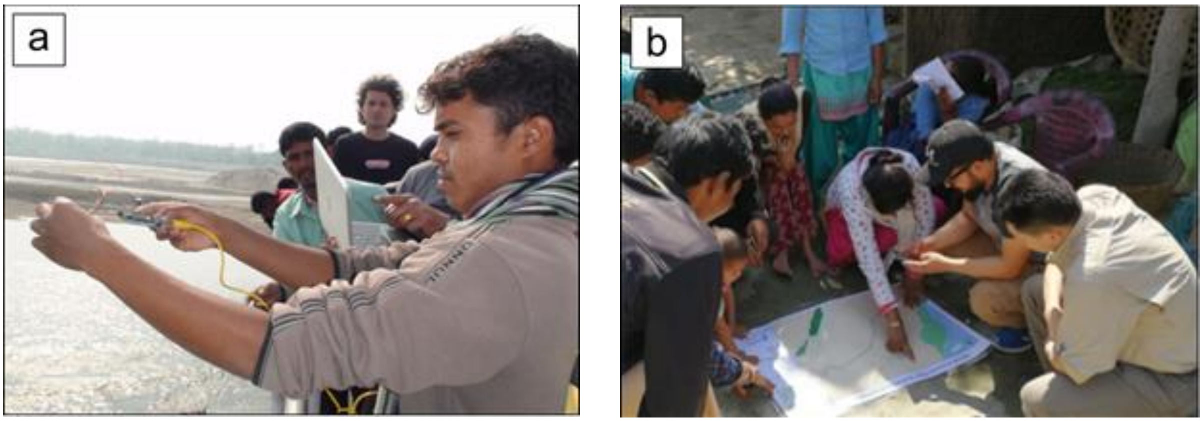
The second type is citizen-facilitated science, where the public gives researchers access to their property, and in turn are engaged in the project, increasing their awareness of science and scientific literacy. An example is a study at the University of Guelph of the interaction between domestic cats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

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

Source: Contribution from the Government of Canada.

In Figure 6, the photographs contrast two different ways in which citizen science has been interpreted within the same area of western Nepal. In the photo (a), citizens serve as data collectors, measuring river level with a bespoke low-cost sensor to inform a local flood early warning system. Photo (b) shows the co-creation of actionable knowledge through a participatory, community-led mapping exercise to identify areas of farmland at risk from landslide activity.

Figure 6. Examples of citizen science in resilience building to natural hazards (flooding and landslides) in western Nepal



Community engagement and collaborative science have generated actionable results in several contexts, from rural areas in western Nepal experiencing multiple vulnerabilities,[171] to urban areas at risk from repeated flooding, like in Bangladesh or southwestern Mozambique.[172] The most effective projects involve two-way information flow over the entire project, which improves citizen

[171] Kattelmann, R. (2003). Glacial lake outburst floods in the Nepal Himalaya: A manageable hazard? *Natural Hazards* 2003; 28:145–54.

[172] For example, see Lane, S.N., Odoni, N., Landström, C., Whatmore, S.J., Ward, N., Bradley, S. (2011). Doing flood risk science differently: An experiment in radical scientific method. *Transactions of the Institute of British Geographers*, 2011, 36(1):15–36).

participation.[173] In many of these projects, situational analyses lead to a prior understanding of local livelihoods, power structures, and institutional frameworks, which enabled the scientific interventions to be better targeted, increasing local buy-in and long-term project sustainability.[174]

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. To take the hydrological realm as an example, this process could take the form of irrigation requirements (for farmers), modelled water uses and demand (for policymakers), or flood vulnerability maps (for the public). Although this important feedback aspect of citizen science is lightly developed,[175] especially in a resilience-building context,[176] Internet-based technologies create opportunities for user feedback and communication beyond the research project itself. 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.[177]

2. Use of technology in citizen science

Many have equated the explosion of citizen science research projects (in resilience building and beyond) with rapid technological and scientific development over the past 10–15 years. As discussed in previous sections, small, inexpensive sensors are now widely available and easy to connect to smartphones, which themselves are generally fully Internet-connected and come with sophisticated cameras as standard. The dramatic pace of this change can be seen in many of the most impoverished communities globally, where access to clean, running water and electricity is lacking, yet the provision of mobile phones is widespread.[178]

These developments, together with advances in knowledge communication and data processing and analysis, are opening new pathways for citizen science to improve resilience-building efforts at a community scale.[179] New ICTs have 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 a community level.

Figure 7 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.

[173] For example, see Karpouzoglou, T., Zulkafli, Z., Grainger, S., Dewulf, A., Buytaert, W., Hannah, D.M. (2016). Environmental Virtual Observatories (EVOs): Prospects for knowledge co-creation and resilience in the Information Age. *Current Opinion in Environmental Sustainability* 2016; 18:40–8.

[174] For example, see Paul, J.D., Buytaert, W., Allen, S., Ballesteros-Canovas, J.A., Bhusal, J., Cieslik K., et al. (2018). Citizen science for hydrological risk reduction and resilience building. *Wiley Interdisciplinary Reviews: Water* 2018; 5: e1262.

[175] For example, see Mueller, M., Tippins, D., Bryan, L. (2012). The future of citizen science. *Democracy and Education* 2012; 20(1):1–12.

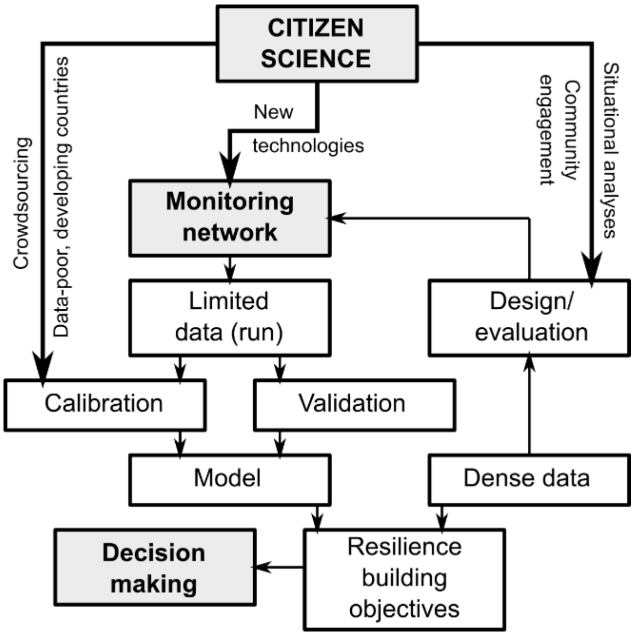
[176] For example, see Rosser, J.F., Leibovici, D.G., Jackson, M.J. (2017). Rapid flood inundation mapping using social media, remote sensing, and topographic data. *Natural Hazards* 2017; 87(1):103–20.

[177] For example, see Liu, Y., Piyawongwaisal, P., Handa, S., Yu, L., Xu, Y., Samuel, A. (2011). *Going beyond citizen data collection with Mapster: A mobile+cloud real-time citizen science experiment*, e-Science Workshops (eScienceW), IEEE 7th International Conference; 2011.

[178] Baum, R.L., Highland, L.M., Lyttle, P.T., Fee, J.M., Martinez, E.M., Wald, L.A. (2014). “Report-a-landslide”: A website to engage the public in identifying geologic hazards. In: Sassa K. et al. (eds.), *Landslide Science for a Safer Geoenvironment* (vol. 2). Cham, Switzerland: Springer; 2014.

[179] Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T.C., Bastiaensen, J., et al. (2014). Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science* 2014; 2:26.

Figure 7. Use of citizen science and new technologies to build resilience in a developmental context



In this example, a monitoring network that leverages some facet of new technology (for instance, measurements of river level using a network of citizens equipped with smartphone cameras) is established, which feeds data into a flood forecasting model. This model is then calibrated by the citizens' records, and validated against existing scientific measurements, to produce an output (for instance, 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 incentivised to suggest improvements or to participate further.

While it is sometimes challenging to integrate the newest forms of innovative hardware directly in resilience-building projects in the least developed countries,[180] promising opportunities nevertheless exist if scientific objectives are combined with a greater understanding of local livelihoods (Table 4).

[180] Paul, J.D., Buytaert, W., Allen, S., Ballesteros-Canovas, J.A., Bhusal, J., Cieslik K., et al. (2018). Citizen science for hydrological risk reduction and resilience building. *Wiley Interdisciplinary Reviews: Water* 2018; 5: e1262.

Table 4. Examples of the use of new technology to build resilience in developing countries at the community level

Technology/innovations	Location(s)	Program objectives	Citizen scientist engagement
Novel sensors to measure rainfall, river level, soil moisture and streamflow, coupled to bespoke modelling approach[181]	Peruvian Andes, Lake Tana (Ethiopia), Mustang (Nepal)	Impact of changing land use and increasing population	Hydrological monitoring
New sensor networks installed at community level[182]	Central Nepal	Rainfall and landslide risk reduction	Rainfall monitoring; geological mapping
Citizen-led UAV mapping and UAV design[183]	Hawaii; Malaysia	Disaster response (volcanoes); impact of land-use change	UAV image submission and map-making
New integrated Mapster smartphone app[184]	Champaign, IL, USA (testing); Burma	Emergency management; urban flood response	Twitter and access to maps (two-way information flow)
OpenStreetMap (OSM)[185]/flood hazard mapping[186]	Nepal	Community empowerment through natural hazard planning	River level measurements; OSM design; risk mapping exercises
Creek Watch: smartphone app and user-friendly website[187]	Northern Mexico	Building flood resilience	Simple observation of water level and flow rate; time-stamped photos
Integration of indigenous knowledge into numerical sea-level models[188]	South Caribbean islands	Improving coastal climate resilience (sea-level change)	Semi-structured interviews; hazard mapping
New crowdsourced datasets and information management platform[189]	Argentina/France /New Zealand	Building flood resilience	Photos and videos for flow estimation

[181] Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T.C., Bastiaensen, J., et al. (2014). Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science* 2014; 2:26.

[182] Malakar, Y. (2014). Community-based rainfall observation for landslide monitoring in western Nepal. In: Sassa K. et al. (eds.), *Landslide Science for a Safer Geoenvironment* (vol. 2). Cham, Switzerland: Springer; 2014.

[183] Johnson, P., Ricker, B., Harrison, S. (2017). *Volunteered drone imagery: Challenges and constraints to the development of an open shared image repository*. Proceedings of the 50th Hawaii International Conference on System Sciences 2017; 1:1995–2004.

[184] Liu, Y., Piyawongwaisal, P., Handa, S., Yu, L., Xu, Y., Samuel, A. (2011). *Going beyond citizen data collection with Mapster: A mobile+cloud real-time citizen science experiment*, e-Science Workshops (eScienceW), IEEE 7th International Conference; 2011.

[185] OpenStreetMap is a collaborative project to create a free editable map of the world, which is available at https://www.openstreetmap.org.

[186] Rieger, C. (2016). *Demonstrating the capacity of online citizen science mapping software to communicate natural hazards and engage community participation*. PhD dissertation, University of Lethbridge, 2016.

[187] Robson, C. (2012). *Using mobile technology and social networking to crowdsource citizen science*. PhD dissertation, University of California, Berkeley; 2012.

[188] De Souza, R.-M., Clarke, J. (2018). *Chapter 11: Advancing coastal climate resilience: Inclusive data and decision-making for small island communities*. Resilience: The Science of Adaptation to Climate Change 2018; 1:143–50.

[189] Le Coz, J., Patalano, A., Collins, D., Guillen, N.F., Garcia, C.M., Smart, G.M., et al. (2016). Crowdsourced data for flood hydrology: Feedback from recent citizen science projects in Argentina, France and New Zealand. *Journal of Hydrology* 2016; 541(B):766–77.

Technology/innovations	Location(s)	Program objectives	Citizen scientist engagement
Citizen seismologists: cloud-based computing tool and website for online learning[190]	Vietnam, Taiwan, Malaysia	Improve knowledge of and resilience to earthquakes	Damage reports and photos, seismograph analysis, shaking reports (using smartphone accelerometers)
Remotely sensed data and VGI[191]	Oxford, UK; Brazil	Flood probability mapping	Geotagged photos from social media
Combination of wireless sensor network and citizen observatories[192]	Sao Carlos, SE Brazil	Integrated river flood risk management	Observational river monitoring
Mobile App - Sensors, Empowerment and Accountability in Tanzania (SEMA App) [193]	Tanzania	Monitoring Rural Water Points	Monitor the functionality status of rural water points

[190] Liang, W.-T., Chen, K.H., Wu, Y.-F., Yen, E., Chang, C.-Y. (2015). Earthquake school in the cloud: Citizen seismologists in Taiwan. *Seismological Research Letters* 2015; 87(1):177–85.

[191] Rosser, J.F., Leibovici, D.G., Jackson, M.J. (2017). Rapid flood inundation mapping using social media, remote sensing, and topographic data. *Natural Hazards* 2017; 87(1):103–20.

[192] Horita, F.E.A., Porto de Albuquerque, J., Degrossi, L.C., Mendiondo, E.M., Ueyama, J. (2005). Development of a spatial decision support system for flood risk management in Brazil that combines volunteered geographic information with wireless sensor networks. *Computers & Geosciences* 2005; 80:84–94.

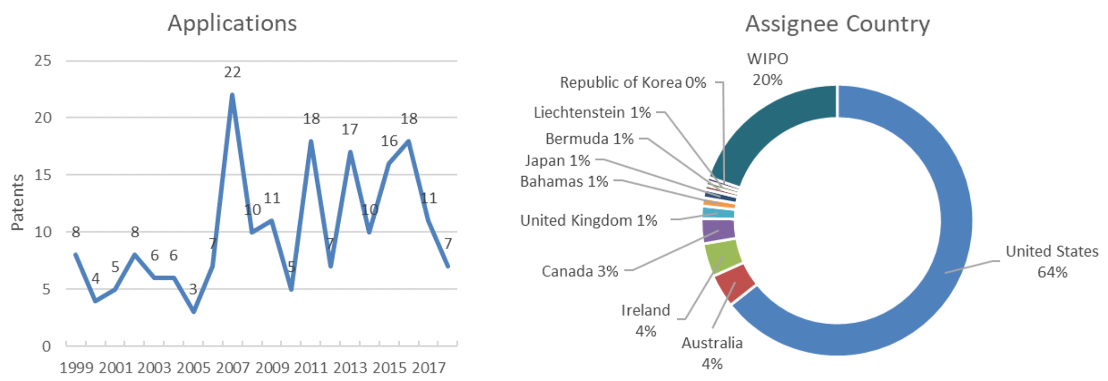
[193] Lemmens, R. L. G., Lungo, J., Georgiadou, P. Y., & Verplanke, J. J. (2017). Monitoring Rural Water Points in Tanzania with Mobile Phones: The Evolution of the SEMA App. *ISPRS international journal of geo-information*, 6(10), 1-20. [316].

V. Innovation: a mission-driven approach to resilience

A. Innovation activity focusing 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 suggest a lack of interest or incentives to engage in invention with this single goal. For instance, an analysis found that, since 1998, only 18 patents were filled explicitly mentioning resilient communities.[194] When including patents related to community-based disaster risk reduction, that number increases to 202 patents since 1995. The number of patent applications per year was in single digits before 2007 and has varied around 12 applications per year recently (Figure 8). However, that number is marginal considering that over 3.1 million patent applications were filled in 2016 alone.

Figure 8. Trends in the number of patents



Source: UNCTAD based on Patsnap data and analytics platform (https://analytics.patsnap.com).

Similarly, an analysis of the technologies listed in the database *WIPO Green*, an interactive marketplace established by the World Intellectual Property Organization (WIPO), shows only 12 listings that mention resilience as one of their characteristics or objectives, covering uses such as intelligent grid technologies and tree support device for planting in the Sahel. These technologies are in the areas of energy (7), farming and forestry (3), green products (1), pollution and waste (1); sourced from the United States (4), Israel (2), Australia (1), China (1) and Niger (1); seven of them at usable level and only two with proven record of commercial use.[195] An analysis of listings of technologies in the UNESCAP Asia-Pacific Centre for Technology Transfer (APCTT) *Technology4SME Database* shows 15 technology offers addressing 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 system for disaster relief and tsunami disaster alert systems.[196]

These relatively low number of inventions and innovations is comprehensible considering that resilience is not an easily defined objective. Commercial research and development efforts rather focus on concrete issues such as communication, construction and health, which have clear demand,

[194] Search using Patsnap analytics (https://analytics.patsnap.com).

[195] Source: search using term "resilience" and category "Technology" (accessed on 23 November 2018 from *WIPO Green* https://www3.wipo.int/wipogreen-database/)

[196] Source: search using term "disaster" (accessed on 23 November 2018 from *APCTT's Technology4SME Database* http://www.apctt.org/technology-transfer)

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 the 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 2014 outbreak of Ebola virus disease in West Africa, where the U.S. Agency for International Development received over 1,500 submissions from innovators around the world about ideas to improve infection control.[197] Contemporary mission-oriented innovation programmes range from national to international, 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.

B. Innovation systems for building resilient communities

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

As discussed in the previous section, the innovation systems for the creation of products and services for building resilient communities are usually mission-driven, meaning that actors in the innovation system pool resources to solve a particular social problem; for example, the need for early warning against hazards, or for functioning communication networks during emergencies. These innovation systems usually focus on later-stage deployment of traditional (e.g. vaccines and remote sensing) or market-ready new technologies (e.g. smartphone apps and low-cost drones), in contrast with early-stage exploration and development of emerging technologies (e.g. AI and CRISPR).

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

- 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 these solutions.
- Civil society organizations are important intermediaries between the producers of scientific knowledge and related technologies and households in the communities,[198] and they can assist in educating and supporting individuals in several aspects of resilience building.[199] Civil society organizations can mediate between local government, technology developers and marginalized groups and promote innovations that address their needs. In many countries, civil society organizations 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 learnt in the design and implementation of STI solutions for community resilience building. Civil society organizations can also mediate

[197] United States Agency for International Development (2015). Fighting Ebola: A Grand Challenge for Development. Available at http://www.ebolagrandchallenge.net/.
[198] Howarth, C., Brooks, K. (2017). Decision-making and building resilience to nexus shocks locally: exploring flooding and heatwaves in the UK. *Sustainability* 2017, 9, 838.
[199] Fitzpatrick, T., Molloy, J. (2014). The role of NGOs in building sustainable community resilience. *International Journal of Disaster Resilience in the Built Environment*, Vol. 5 Issue: 3, pp.292-304.

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).[200]

- Social entrepreneurs contribute to the innovation process by providing local solutions in response to local social, cultural and environmental problems.[201] They help to build resilient communities by addressing existing vulnerabilities and by promoting sustainable transitions.
- Effective education systems increase the capacity of communities to learn, adapt to changes and to contribute to the innovation process of finding new and better solutions to the challenges of disaster risk reduction and the Sustainable Development Goals. Science communication is very important to increase the capacity of communities to use existing knowledge.
- 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).[202]
- The national government is key to provide direction for the mission-oriented approach to innovation, provide the required soft and hard public infrastructure, promote capacity building and foster the creation of linkages in the innovation system.

Effective innovation systems have robust and evolving linkages among all these STI stakeholders. For example, the cooperation between science and technology groups and educational institutions to promote the popularization and dissemination of resilience knowledge and self and mutual rescue skills, and foster education resources on disaster risk reduction. Another link is the cooperation between the science and technology groups and governments, communities and other stakeholders to promote the popularization and application of the scientific knowledge and technological solutions (for examples, see Box 16 and Box 17).

Box 16. Developing a knowledgeable society about science in South Africa

In 2015, the Department of Science and Technology (DST) of South Africa adopted the Science Engagement Strategy (SES) 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. DTS 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 to put this in a global perspective.

Source: Contribution from the Government of South Africa.

[200] For example, see Georgiadou, Y., Lungo, J.H., Richter, C. (2014). Citizen sensors or extreme publics? Transparency and accountability interventions on the mobile geoweb. *International Journal of Digital Earth*, 7(7), pp. 516-533.

[201] Berno, T. (2017). Social enterprise, sustainability and community in post-earthquake Christchurch: Exploring the role of local food systems in building resilience. *Journal of Enterprising Communities: People and Places in the Global Economy*, Vol. 11 Issue: 1, pp.149-165.

[202] Howarth, C., Brooks, K. (2017). Decision-making and building resilience to nexus shocks locally: exploring flooding and heatwaves in the UK. *Sustainability* 2017, 9, 838.

Box 17. Making scientific findings and tools available to communities to enable resilience in the United States

In the United States, it is a Federal priority to make scientific findings and tools available to communities to enable resilience. The National Oceanic and Atmospheric Administration's (NOAA) "Weather-ready Nation" Program 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 NOAA design and deploy their products. Similarly, the National Institute of Standards and Technology's (NIST) Community Resilience Program translates scientific findings into tools and metrics to help communities develop strategies to achieve resilience. Stakeholder engagement is an important aspect of this NIST Program, to ensure that the products developed are as useful and effective as possible.

Source: 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, generational, and income 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 resilient 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 building the required skills to use the enabling technologies, such as ICT, and on the dissemination of resilience knowledge through the education system. Social and cultural norms and practices should promote inclusive participation of women, youth and the elderly, in the innovation process towards community resilience.

C. New innovation approaches for community resilience[203]

New technologies open the opportunity to tap into the potential of large segments of the population of developing countries, including the youth, who have not been considered by traditional innovation policies. That is why growing attention is being given to several new approaches to innovation.[204] 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.[205]

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

[203] This section draws on: UNCTAD. (2017) New Innovation Approaches to Support the Implementation of the Sustainable Development Goals. *Science, Technology and Innovation Current Studies Report*. United Nations: New York and Geneva.

[204] UNCTAD (2017). *New innovation approaches to support the implementation of the Sustainable Development Goals*. UNCTAD/DTL/STICT/2017/4.

[205] Fu, X. et al. (2014). Innovation in Low Income Countries: A Survey Report. *Technology and Management Centre for Development*. Oxford University. Fu, X. (2018). *Innovation under the radar in Africa*. Cambridge University Press.

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 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.[206]

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 social movements and networks of academics, activists and practitioners experimenting with alternative forms of knowledge-creation and innovation processes.[207] For example, community-based disaster risk reduction systems (e.g. risk investigation, education and training, landslide monitoring, information analysis, early warning system and emergency response) usually engage the community in the development of monitoring and early warning mechanisms.[208] Another example is the development of innovative mobile payment solutions especially for the consumers at the Bottom of the Pyramid (BoP), using basic mobile phone technology rather than smartphones.[209] 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.[210] 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,[211] the promotion of new local business ideas for diversification of livelihoods,[212] and support to women's eco-entrepreneurship as an approach for sustainable local rural development.[213]

[206] UNCTAD, (2014). Transfer of technology and knowledge-sharing for development: Science, technology and innovation issues for developing countries. UNCTAD Current Studies on Science, Technology and Innovation, No. 8, Geneva.

[207] Fressoli, M. et al. (2014). When grass-roots innovation movements encounter mainstream institutions: Implications for models of inclusive innovation. *Innovation and Development*. 4(2):277–292.

[208] For example, see Liu, Y., Yin, K., Chen, L., Wang, W., Liu, Y. (2016). A community-based disaster risk reduction system in Wanzhou, China. *International Journal of Disaster Risk Reduction* 19, pp. 379-389.

[209] For example, see Gaur, A., Avison, D., Malaurent, J. (2014). *Together we will find a 'Jugaad': Resource bricolage in the Indian mobile payments sector*. 20th Americas Conference on Information Systems, AMCIS 2014.

[210] Van der Have RP and Rubalcaba L (2016). Social innovation research: An emerging area of innovation studies? *Research Policy*. 45(9):1923-1935. Available at http://dx.doi.org/10.1016/j.respol.2016.06.010.

[211] For example, see Ullah, I., Khan, M. (2017). Microfinance as a tool for developing resilience in vulnerable communities. *Journal of Enterprising Communities* 11(2), pp. 237-257.

[212] For example, see Quaranta, G., Brandt, J., Salvia, R. (2016). The Local Food Processing House: A social innovation for rural development in Campania. *Rivista di Studi sulla Sostenibilita* (2), pp. 227-236.

[213] For example, see Pallarès-Blanch, M. (2015). Women's eco-entrepreneurship: A possible pathway towards community resilience? | [Eco-emprendimiento de mujeres: ¿un posible camino en resiliencia social?]. *Ager* (18), pp. 65-89.

VI. Key challenges

A. 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, complex data download, processing, and storage techniques. Moreover, their positioning in often harsh, remote, and inhospitable environments frustrates routine site maintenance. Given pressures on funding, the acquisition and management of such data have regularly been de-prioritised, particularly in Africa, leading to large numbers of redundant or abandoned stations.[214]

Crowdsourcing data may be a solution, but there are many challenges that must be considered. In general, it is difficult to broadly share, validate, and integrate crowdsourcing inputs into response operations and existing reporting channels. There are also misconceptions on the validity and veracity of crowdsourced data; about which training and more practical experience for both users and policymakers could help. In addition, there is an untapped potential for communities to leverage existing national crowdsourcing and citizen science projects before, during, or after disasters.

For example, citizen science data, once collected, have the potential to plug such data gaps (especially 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 here is *potential*. At present, many projects that exploit citizen science data, such as the EU-funded WeSenseIt and GroundTruth programmes, exist only as proofs of concept.[215] Both projects aim to leverage crowdsourced observations to improve flood forecasting applications; yet they acknowledge that operationalising such new data acquisition strategies, for instance in a disaster risk reduction environment, is not a primary objective.[216]

To better leverage that data, effort should be directed at creating data standards and frameworks that facilitate the collection and dissemination of that data. For example, an integral component of citizen science resilience-building projects would typically involve sensor-sourced data collection by non-scientists, the design of the sensor network may need to be technically simplified so that self-consistent samples can be taken.[217] Data conversion between technologies, platforms and applications would also increase the use of the data. For example, while the use of smartphones to photograph flooding extent and river level has the potential to form a very dense network of crowdsourced sensors, the data conversion to input for numerical models, as well as the provision of

[214] Paul, J.D., Buytaert, W., Allen, S., Ballesteros-Canovas, J.A., Bhusal, J., Cieslik K., et al. (2018). Citizen science for hydrological risk reduction and resilience building. *Wiley Interdisciplinary Reviews: Water* 2018; 5: e1262.
[215] Horita, F.E.A., Porto de Albuquerque, J., Degrossi, L.C., Mendiondo, E.M., Ueyama, J. (2005). Development of a spatial decision support system for flood risk management in Brazil that combines volunteered geographic information with wireless sensor networks. *Computers & Geosciences* 2005; 80:84–94.
[216] For example, see Solomatine, D., Mazzoleni, M., Alfonso, L., Chacon Hurtado, J.C. (2017). *Towards socio-hydroinformatics: optimal design and integration of citizen-based information in water-system models*. Proceedings of the 19th EGU General Assembly 12370; 2017; and Galimberti, G., Balbo, A. (2017). *New possibilities in hydrological monitoring offered by experiences of Citizen Science: CITHYD, a web application for hydrometric measurements in rivers*. Proceedings of the 19th EGU General Assembly 8102; 2017.
[217] Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T.C., Bastiaensen, J., et al. (2014). Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science* 2014; 2:26.

information back to volunteers, remain technologically demanding and are under active development.[218]

An additional challenge is that these data are very often of lower quality and more temporally sparse compared to 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 instance between citizen science-collected rain gauge data and satellite precipitation products, to create combined datasets.[219] However, guidance on the deployment, use, and management of these data collection services, particularly by those outside of the professional scientific realm, remains limited.[220]

Citizen science can overcome the challenges of high observational costs and limited spatial coverage of traditional monitoring networks,[221] 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. Indeed, 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 characterised as explicitly and transparently as possible, for instance by providing uncertainty bounds. These could take the form of approximate percentage errors on river level as deduced with a smartphone camera; or a basic quantification of bias if precipitation were recorded under sub-optimal conditions, for example, in the rain shadow of a tree. Despite the rapid technological advances, citizen science data are rarely presented in such a form due to the inherent difficulties in uncertainty quantification.[222]

With the use of social media for building resilience, there are issues that require consideration related to the reliability of information, matters of privacy and data protection and the nature of the content published in social media.[223] Data in general, either when used in humanitarian and disaster emergency contexts or in the context of preparedness, raises the need for operationally responsible data approaches, as well as the tension between information sharing and data privacy.[224] In this

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[218] Karpouzoglou, T., Zulkafli, Z., Grainger, S., Dewulf, A., Buytaert, W., Hannah, D.M. (2016). Environmental Virtual Observatories (EVOs): Prospects for knowledge co-creation and resilience in the Information Age. *Current Opinion in Environmental Sustainability* 2016; 18:40–8.

[219] For example, see Grimes, D.I.F., Pardo-Iguzquiza, E., Bonifacio, R. (1999). Optimal areal rainfall estimation using rain gauges and satellite data. *Journal of Hydrology* 1999; 222(1):93–108; and Manz, B., Buytaert, W., Zulkafli, Z., Lavado, W., Willems, B., Alberto Robles, L., et al. (2016). High-resolution satellite-gauge merged precipitation climatologies of the Tropical Andes. *Journal of Geophysical Research: Atmospheres* 2016; 121(3):1190–1207.

[220] For example, see Lundquist, J.D., Cayan, D.R., Dettinger, M.D. (2013). Meteorology and hydrology in Yosemite national park: A sensor network application. *Information Processing in Sensor Networks*, Proceedings 2013; 2654:518–28.; and Chacon-Hurtado, J.C., Alfonso, L., Solomatine, D.P. (2017). Rainfall and streamflow sensor network design: a review of applications, classification, and a proposed framework. *Hydrology and Earth System Sciences* 2017; 21(6):3071–91.

[221] For example, see Davids, J.C., van de Giesen, N., Rutten, M. (2017). Continuity vs. the Crowd: Tradeoffs between Continuous and Intermittent Citizen Hydrology Streamflow Observations. *Environmental Management* 2017; 60:12., and Mazzoleni, M., Verlaan, M., Alfonso, L., Monego, M., Norbiato, D., Ferri, M., et al. (2017). Can assimilation of crowdsourced data in hydrological modelling improve flood prediction? *Hydrology and Earth System Sciences* 2017; 21:839–61.

[222] For example, see Buytaert, W., Dewulf, A., De Bièvre, B., Clark, J., Hannah, D.M. (2016). Citizen science for water resources management: Toward polycentric monitoring and governance? *Journal of Water Resources Planning and Management*, 2016;142(2):01816002.

[223] Hokkanen, L. (2016). Harnessing social media for safety. Injury Prevention 2016; 22: A123.

[224] Chana, J., Batemana, L., Olafssona, G. (2016). A people & purpose approach to humanitarian data information security and privacy. *Procedia Engineering* 159 (2016) 3–5.

regard, there is a need for prudent use of data acquired during the rapid land surveying of developing countries and for action to protect citizens' privacy.[225]

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, flood early-warning systems, and water quality testing).[226] Several such projects have already successfully integrated participatory data collection as a means to expand the observational database in both space and time.[227]

Many top-down institutional research techniques have struggled to create "actionable" knowledge at a local level. For instance, 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 confines it 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.[228]

Linking data collection, analysis, and information dissemination together via user-friendly (online) interfaces or apps is strongly advocated by the Sendai Framework on Disaster Risk Reduction in 2015. 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 (EVOs)[229] which allow information to flow freely between multiple actors. Such EVOs have only very recently developed to highlight the ways in which data co-generation potentially leads to political empowerment of marginalised 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 the access to communications networks (such as Wi-fi or the Internet) and equipment at the community level. For example, the citizen science approach emphasises 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 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 in the case of mobile phones, there is a prevalence of older smartphones in some regions, countries, and demographic groups, which may not interface with the latest applications. From a technical perspective, regions with low Internet penetration can benefit from far-reaching mobile phone

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[225] Haarsma, D., & Georgiadou, P. Y. (2017). Geo-ethics Requires Prudence with Private Data: GIM International interviews Professor Yola Georgiadou. *GIM International*, 31(10), 16-19.

[226] For example, see Banik, B.K., Alfonso, L., Di Cristo, C., Leopardi, A., Mynett A. (2017). Evaluation of different formulations to optimally locate sensors in sewer systems. *Journal of Water Resources Planning and Management* 2017; 143(7):04017026.

[227] For example, see McCulloch, J., McCarthy, P., Guru, S.M., Peng, W., Hugo, D., Terhorst, A. (2008). Wireless sensor network deployment for water use efficiency in irrigation. *Proceedings of the Workshop on Real-world Wireless Sensor Networks* 2008.

[228] For example, see Paul, J.D., Buytaert, W., Allen, S., Ballesteros-Canovas, J.A., Bhusal, J., Cieslik K., et al. (2018). Citizen science for hydrological risk reduction and resilience building. *Wiley Interdisciplinary Reviews: Water* 2018; 5: e1262.

[229] For example, see Buytaert, W., Dewulf, A., De Bièvre, B., Clark, J., Hannah, D.M. (2016). Citizen science for water resources management: Toward polycentric monitoring and governance? *Journal of Water Resources Planning and Management*, 2016;142(2):01816002.

coverage for sensor data transmission via text messaging.[230] An important component of the digital infrastructure is the availability of local business that can support and maintain that infrastructure, both in relation to software and hardware. Therefore, initiatives to foster and promote such ecosystems of local ICT firms are needed.

B. Social challenges: Knowledge generation and use

Members of a community have different levels of resilience, which are influenced by actions and policies at individual, local, regional, national, and even international, scales. Their 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.[231]

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 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 technologies, they can devote more time to activities such as education, paid work, political and public participation, and leisure activities, that enhance the quality of life for entire communities. It is especially 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.[232] An example is the project focusing on women and youth empowerment in Kibera slums in Kenya, specifically by engaging the community in data and information gathering as well as training in ICT, entrepreneurship, disease vaccine trials (e.g. HIV/Aids and malaria) and undertaking research in orphanages to enable them harness and utilize innovations (see Box 18).

In citizen science projects, volunteer recruitment and engagement throughout the project duration remain a challenge, with possible solutions including the development of a 'ranking system', or the identification and promotion of particularly able volunteers.

Another non-technical factor that affect the uptake of citizen science data, especially in developing (and the least developed) countries, is that the proposals of non-scientist knowledge may not adhere to the often-rigid institutionalised processes through which knowledge is collected (e.g. national networks of seismographs established with bilateral aid).[233] Studies suggest a higher rate of success of initiatives that combine informal sanctions and rewards and their formal counterparts.[234] Nevertheless, when these mechanisms are not devised in a participatory way by all actors involved, it

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[230] Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T.C., Bastiaensen, J., et al. (2014). Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science* 2014; 2:26.

[231] Roberts, E., Farrington, J., Skerratt, S. (2015). Evaluating New Digital Technologies Through a Framework of Resilience. *Scottish Geographical Journal*, 131(3-4), pp. 253-264

[232] For example, see Khalafzai, A.K., Nirupama, N. (2011). Building Resilient Communities through Empowering Women with Information and Communication Technologies: A Pakistan Case Study. *Sustainability* 2011, 3, 82-96.

[233] Birkenholtz, T. (2008). Contesting expertise: the politics of environmental knowledge in northern Indian groundwater practices. *Geoforum* 2008; 39:466–82.

[234] Katomero, J. G., & Georgiadou, P. Y. (2018). The Elephant in the Room: Informality in Tanzania's Rural Waterscape. *ISPRS international journal of geo-information*, 7(11), 1-21. [437].

may be difficult for the proposals of non-scientist local stakeholders to feed into the decision making by national institutions like agricultural or hazard response agencies.

Box 18. Angaza community project in Kenya

The Angaza community project Project in Kibera, a slum of Nairobi city, targets women and youth empowerment through the following objectives: a) to promote health education and enhance prevention of diseases and illnesses including response to HIV/AIDS among the infected and affected; b) to empower women and youth economically through equipping them with relevant skills and knowledge in microfinance and resource mobilization; c) improved literacy levels among the children, youth and adults through support of formal vocational trainings; and d) 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 facing the Angaza Community project include the high incidence of poverty and increasing population growth. Kibera is estimated to be the largest slum in Africa with a population nearing 1.7 million people living in a 2 miles radius, and the population is majorly poor. It is a most crowded settlement, and its population density is estimated at about 36 square feet per person. Kibera has very little or no infrastructure with open sewers and drains everywhere. Kibera slum experiences open sewage, open garbage dumps, mud-walled houses and many more eyesores. It lacks adequate schools and hospitals to meet the demand. Even though located in an urban area, Kibera lacks adequate electricity, running water, decent housing and most importantly food. Despite these miserable conditions, Kibera is an environment booming with small-scale business activities of every kind.

The project is working towards developing the entrepreneurship skills of the community to get women and youth out of the cycle of poverty. This way the project contributes towards addressing part of the Sustainable Development Goals (SDGs) Kenya Vision 2030. Specifically, the STI component includes engaging the community in data/information gathering as well as training in ICT, entrepreneurship, disease vaccine trials (HIV/Aids, and malaria.

Source: Contribution from the Government of Kenya.

Data collection is becoming increasingly multi-tiered, involving increased diversity in terms of actors, purposes, and tailored, multi-objective networks. These developments are sometimes precluded by cultural differences (e.g. language, customs, hierarchies, gender and treatment of 'outsiders') between scientists and local stakeholders.[235] This could become more challenging when designing and implementing transboundary monitoring systems involving governmental and non-governmental actors across various political jurisdictions.[236] Poor social cohesion within the communities themselves sometimes causes a lack of trust in the ability of the research project to achieve its stated goals. People management issues and the very large scale of some citizen science projects have also the potentially greatest negative impact on data quality and dissemination.[237]

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[235] For example, Solomatine, D., Mazzoleni, M., Alfonso, L., Chacon Hurtado, J.C. (2017). *Towards socio-hydroinformatics: optimal design and integration of citizen-based information in water-system models*. Proceedings of the 19th EGU General Assembly 12370; 2017.

[236] For example, see Chandran, R., Hoppe, R., De Vries, W.T., Georgiadou, Y. (2015). Conflicting policy beliefs and informational complexities in designing a transboundary enforcement monitoring system. *Journal of Cleaner Production* 105, pp. 447-460.

[237] Gura, T. (2013). Citizen science: Amateur experts. *Nature* 2013; 496:259–261.

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 itself.[238] Moreover, many natural hazard- and demographic-related data, such as 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 that the data and generated knowledge 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; they depend upon a profound understanding on the part of individual non-scientists of the generated information.[239] A major pitfall to be avoided is that citizen science-generated data remain not being exploited (e.g. fed into numerical models), instead of being transformed into useful output for non-scientist stakeholders at the community level (e.g. hazard maps relating to landslide or earthquake vulnerability), let alone communicated back to the affected communities themselves.

Standardization of tools and methods used in citizen science could also help to reduce operational challenges of these 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 certain cases, it has been reported a mismatch 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, regulatory and frameworks that do not entrust the responsibility to local government for acting upon that information.[240] The answer to this would be a decentralization of the responsibilities in managing disaster risk reduction. [241]

The clash between the way in which 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.[242] 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. Scientists also lack time and money to fully understand local language and dialects, social norms, and livelihood situation. At the same time, local stakeholders consider resilience building as having a measurable impact on livelihood, but they lack trust or have 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 involve local

[238] Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T.C., Bastiaensen, J., et al. (2014). Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science* 2014; 2:26.

[239] For example, see Paul, J.D., Buytaert, W., Allen, S., Ballesteros-Canovas, J.A., Bhusal, J., Cieslik K., et al. (2018). Citizen science for hydrological risk reduction and resilience building. *Wiley Interdisciplinary Reviews: Water* 2018; 5: e1262.

[240] Howarth, C., Brooks, K. (2017). Decision-making and building resilience to nexus shocks locally: exploring flooding and heatwaves in the UK. *Sustainability* 2017, 9, 838.

[241] For example, see Malalgoda, C., Amaratunga, D. (2015). A disaster resilient built environment in urban cities: The need to empower local governments. *International Journal of Disaster Resilience in the Built Environment*, Vol. 6 Issue: 1, pp.102-116.

[242] For example, see Buytaert, W., Zulkafli, Z., Grainger, S., Acosta, L., Alemie, T.C., Bastiaensen, J., et al. (2014). Citizen science in hydrology and water resources: opportunities for knowledge generation, ecosystem service management, and sustainable development. *Frontiers in Earth Science* 2014; 2:26.

stakeholders fully, from problem definition to data analysis and interpretation, and final dissemination of results and information communication interfaces.[243]

Technology-driven citizen science projects to boost resilience are recommended to include a social science (rather than solely engineering or physical science) component; such 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-local stakeholder meetings or workshops has been shown to surmount intra-community cultural challenges and issues of trust.[244] The most effective of these 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.

C. Market challenges: scalability and sustainability

A critical challenge for the innovation systems for building resilient communities is that many of the solutions are not developed beyond the prototyping 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.

In terms of the use of hardware like drones and sensor networks in community-led resilience building, current operational deployments are of relatively modest scale, rarely beyond the scale of small, isolated villages.[245] Some of the challenges are the limitations of off-the-shelf components that are usually not designed for the intended purpose of capacity building; a lack of suitable sensors; and the cost of deployment and data collection, which remains high in areas of interest that are often highly remote and impoverished. Moreover, important application-specific requirements may not be well catered for by using off-the-shelf components (e.g. variable sampling rates, well-defined and flexible sensor interfaces, ease of deployment, and network models for the broader environment).

Another challenge is the engagement and coordination of efforts across different governmental areas, sectors, markets (e.g. health, infrastructure, education), which are required to upscale solutions for resilience building that usually have multiple impacts in different areas of the SDGs. For example, the sustainability of citizen science projects depends, in part, on the motivational factors of the non-scientist stakeholders, which creates an added layer of uncertainty in terms of their sustainable integration in longer-term capacity building projects.

Recovery strategies implemented without a careful study of unintended consequences could also affect resilience and can lead to increased social vulnerability. For example, in coastal fishing communities in Sri Lanka after the 2004 Indian Ocean Tsunami, relief groups delivered new boats and fishing equipment in such quantity that there were more fishing vessels soon after than before the tsunami. As a consequence, vulnerability to fishery collapse increased in an area where fisheries were

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[243] For example, see Paul, J.D., Buytaert, W., Allen, S., Ballesteros-Canovas, J.A., Bhusal, J., Cieslik K., et al. (2018). Citizen science for hydrological risk reduction and resilience building. *Wiley Interdisciplinary Reviews: Water* 2018; 5: e1262.

[244] For example, see Davids, J.C., van de Giesen, N., Rutten, M. (2017). Continuity vs. the Crowd: Tradeoffs between Continuous and Intermittent Citizen Hydrology Streamflow Observations. Environmental Management 2017; 60:12.

[245] For example, see Kerkez, B., Glaser, S.D., Bales, R.C., Meadows, M.W. (2012). Design and performance of a wireless sensor network for catchment-scale snow and soil moisture measurements. *Water Resources Research* 2012; 48(9):1944–73; and Zhang, J., Shan, L., Hu, H., Yang, Y. (2012). Mobile cellular networks and wireless sensor networks: toward convergence. *IEEE Communications Magazine* 2012; 50(3):164–9.

already thought to be stressed and where decreasing in catch by subsistence fishing directly affects the main source of protein for many people.[246]

D. Developing resilient STI solutions

Technology solutions should also be resilient itself. In the case of those focusing on emergency response, they should be able to withstand weather, wear, pressure and damage. They should also be power-efficient and increasingly leverages innovative sources of energy, supported by a network of redundant products and services, with which it is 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 of people's resilience to economic, social and environmental shocks. By damaging the infrastructure and its functionality, disasters also impact the socio-economic fabric of communities.

Disruption of critical infrastructure, such as hospitals, transport, electricity and ICT infrastructure, causes major negative effects on the economy and functioning of society (see Box 19).

The complex nature and high interconnectedness of many of these infrastructures make them particularly vulnerable to "chain reaction" effects during a crisis.[247] 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 the network that are already well connected.[248] These networks are robust to random failure but vulnerable to failure on nodes with many links. Public transport networks, for example, seem to be robust under random failure but vulnerable to more targeted shocks that disrupt nodes that are more connected or more central in terms of having the largest influence on the available paths in the network.[249] Other infrastructure may also be affected in this way depending on their structure. For instance, a review of studies of robustness of power grids using complex network concepts has found that most of them are vulnerable to targeted attacks on the most connected nodes and robust to random failure. In this respect, strategies to improve robustness include restricted link addition, microgrids and smart grids.[250]

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[246] De Silva, DAM and M Yamao (2007), Effects of the tsunami on fisheries and coastal livelihood: A case study of tsunami-ravaged southern Sri Lanka. *Disasters*, 31(4): 386–404; and Subasinghe, S. (2005) Sri Lanka: *Assessment of rehabilitation and re-construction needs in the tsunami affected post-harvest fisheries sector*. FAO, Rome.

[247] For example, see Van Eeten, M; Nieuwenhuijs, A.; Luiijf, E.; Klaver, M. and Cruz, E. (2011). The state and the threat of cascading failure across critical infrastructures: the implications of empirical evidence from media incident reports. *Public Administration* 89(2) 381-400.

[248] For a review of the literature, see Derrible, S, and Kennedy, C (2011). Applications of Graph Theory and Network Science to Transit Network Design. *Transport Reviews*, 31, 4, pp. 495-519.

[249] Berche, B., von Ferber, C., Holovatch, T., and Holovatch, Yu. (2009) Resilience of public transport networks against attacks. *The European Physical Journal* B. 71, 125–137.

[250] Cuadra, L, Salcedo-Sanz, S, Del Ser, J, Jiménez-Fernández, S, & ZongWoo, G (2015). A Critical Review of Robustness in Power Grids Using Complex Networks Concepts. *Energies* (19961073), 8, 9, pp. 9211-9265.

Box 19. Safe Hospitals Programme

The WHO's Safe Hospitals Programme has the objective to safeguard health facilities and ensure they are always functional, including in emergency situations. If a health facility is assessed as being unsafe, posing a threat to health or liable not to function in an emergency based on WHO's Hospital Safety Index, retrofitting, for example, should be considered to improve its resilience.

In Nepal, a study found that spending US$150,000 on non-structural mitigation measures in nine hospitals – securing equipment and medicines – made them better able to function post-earthquake. This is the reason why in the April and May 2015 Nepal earthquakes, when the first earthquake struck on 25 April 2015 measuring 7.8 on the Richter scale and the second earthquake hit on 12 May 2015 measuring 7.3, both failed to disrupt services at Kathmandu's largest public hospitals, including Tribhuvan University Teaching Hospital (TUTH), Patan Hospital, Civil Service Hospital, Birendra Army Hospital and the trauma centre at Bir Hospital. The Ministry of Health and Population, Nepal and WHO have had in place for more than a decade intervention to ensure that key hospitals, health facilities and health workers would be able to withstand earthquakes, ready and able to function well in an emergency.

Source: Based on a contribution from the WHO.

VII. Science, technology and innovation policies for building resilient communities

Science, technology and innovation policies for building resilient communities should focus on strategies and mechanisms that create the enabling environment for the mission-driven and late-stage deployment approaches that are characteristic of this innovation system. These 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 engagement of academy and civil society organizations with the private sector to facilitate the upscale of the solutions. Therefore, instead of the traditional emphasis on R&D, FDI and trade as sources of innovation and technological knowledge, the focus shifts 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.

Policies should coordinate the provision of required infrastructure for the innovative community-based solutions, including national data and information infrastructure for resilience (see Box 20 for an example from Chile, and Box 21 for an example from Japan). Policies should also promote the development of firms providing services related to enabling technologies such as ICTs (see Box 22 for an example from Iran). With the complex nature of disasters, there is the need for policy to promote resilient ICT infrastructure to reduce the risk of natural hazards triggering technological disasters (NATECH).

In addition, STI policies should also help to build resilience against potential negative economic, social and environmental effects caused by the disruptive innovations, such as the potential impact on jobs of productive sectors using automation, artificial intelligence and robots. This objective could be pursued through policies that promote building skills and productive capacity in these frontier technologies, to increase societal readiness to adapt to innovations using these technologies. It is also important to build foresight capacity for early detection of potentially disruptive innovations, which could help to better target proactive interventions (see Box 23 for an example of the foresight process in this context).

Box 20. Chile's R&D and Innovation Strategy for Resilience against Disasters of Natural Origin

The Chilean Natural Disasters Commission, under the National Council for Innovation and Development, proposed in 2016 a National R & D & I Strategy for Resilience against Disasters of Natural Origin (CREDEN), which budget is US $ 45.7 million per year. With this strategy, it is expected that each year on average, the country will save up to US $ 106 million through the lower losses associated with disasters of natural hazards. The strategy is associated with five enabling conditions: (i) a new institutional framework (ii) a modern national data and information infrastructure for resilience¸ (iii) an advanced human capital development program in the area of risk and resilience; (iv) the development of five national knowledge and manufacturing laboratories; and (v) an outreach program towards society based on the generated R&D and innovation.

Source: Contribution from the Government of Chile.

Box 21. Japan's Resilience Disaster Information System

In Japan, as part of its Cross-Ministerial Strategic Innovation Promotion Program, the government is developing 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 is a five-year project (2014-2018), and the 2017 budget was of ¥2.3 Billion. The system will provide prediction solutions, including forecasting technologies for tsunami, and heavy rain and tornado. It will also support response to natural disasters through ICT-based information sharing and application technology, disaster information collection system and 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: Contribution from the Government of Japan.

Box 22. Example of support for creating local services on ICTs

Iran Vice-Presidency for Science and Technology (VPST) and Ministry of ICT have several initiatives and incentives to support the establishment and expansion of ICT-based start-ups and SMEs. Society and crisis are among key priorities to get support. VPST provides a variety of supports through "the law for supporting knowledge-based firms" and "creative and cultural industries council". ICT Startups Empowerment and Facilitation Center (ISEFC), an affiliated body to the Ministry of ICT, also has several initiatives to support building resilient communities through digital technologies and STI in general.

Source: Contribution from the Government of Iran (Islamic Republic of).

Box 23. Increasing societies' readiness for disruptive innovation

A way to build resilient communities can be through enhancing society's readiness for disruptive technological changes. It is known that demand from "lead users" are crucial for defining 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 R&D projects in the national Smart Manufacturing Technology Roadmap 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: Contribution from the Government of Turkey.

VIII. International collaboration

International collaboration plays a critical role in the provision of global STI that enables community-based technological solutions for resilience building. This collaboration generates information on cross-border natural hazards such as weather events or disease outbreaks, which feeds into national and community-level services. For example, the World Meteorological Organization (WMO) provides online information on tropical cyclones, heavy rain and snow, thunderstorms, gale and fog.[251] The United Nations Platform for Space-based Information for Disaster Management and Emergency Response (UN-SPIDER) makes available space-based scientific knowledge and technologies for disaster management.[252] In the area of health, the Pandemic Influenza Preparedness Framework (PIP Framework) coordinated by the WHO allows the rapid collection and analysis of influenza viruses, increasing national preparedness capacities and equitable access to antivirals and vaccines (See Box 24).[253]

Collaborative global research platforms advance the development of scientific tools that contribute to resilience. For example, the *PrecisionFDA*[254] connects experts around the world and provides tools, data, and a framework for running community-based challenges. An example is the CDRH Biothreat Challenge focusing on early detection during pathogen outbreaks (e.g., Ebola outbreaks in West Africa).[255] Collaborative platforms are also effective in engaging governments and practitioners. For example, the *100 Resilient Cities*[256] platform provides member cities with financial and logistical guidance and curated resilience-building tools and services. Another example is the *Digital Humanitarian Network*,[257] which leverage 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 as well as performing research on citizen science. These include the European Citizen Science Association (ECSA),[258] and the Citizen Science Association (CitizenScience.org),[259] and the Australian Citizen Science Association (ACSA).[260] In 2017, the *Citizen Science Global Partnership*, a network-of-networks, was launched to promote and advance citizen science.[261]

[251] For more information, see: https://severe.worldweather.wmo.int/
[252] For more information, see: http://un-spider.org/
[253] For more information, see: http://www.who.int/influenza/pip/en/
[254] For more information, see: https://precision.fda.gov/
[255] For more information, see: https://precision.fda.gov/challenges/3
[256] For more information, see: http://www.100resilientcities.org/
[257] For more information, see: http://digitalhumanitarians.com/
[258] For more information, see: https://ecsa.citizen-science.net/
[259] For more information, see: https://www.citizenscience.org/
[260] For more information, see: https://csna.gaiaresources.com.au/
[261] For more information, see: http://citizenscienceglobal.org/

Box 24. Pandemic Influenza Preparedness Framework

The Pandemic Influenza Preparedness Framework or 'PIP Framework' is a partnership between the major players in international response to pandemic influenza. The PIP Framework has two objectives: (a) improve the sharing of influenza viruses with the potential to cause a human pandemic; and (b) establish more predictable, efficient, and equitable access to the benefits that result from the sharing of such viruses, notably vaccines and antiviral medicines.

WHO coordinates the sharing of influenza viruses through an international network of public health laboratories called the 'Global Influenza Surveillance and Response System' (GISRS). 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 ('IVPP") for global monitoring, risk assessment and the development of safe and effective pandemic influenza vaccines.

The PIP Framework was unanimously adopted by the 194 Member States of the WHO during the World Health Assembly on 24 May 2011. More than 140 National Influenza Centres (NICs) in the GISRS, collaborate on a continuous basis to collect and test specimens for influenza viruses – both seasonal viruses and IVPP. Under the PIP Framework, countries are expected to support their NICs and ensure that they share IVPP in a rapid, systematic, and timely manner with a small number of specialized laboratories within GISRS.

These specialized laboratories perform molecular testing and other advanced analyses. GISRS laboratories 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 IVPP might evolve into pandemic viruses. An internet-based tool called the Influenza Virus Traceability Mechanism (IVTM) is used to track the sharing of IVPP and other materials, collectively known as PIP Biological Materials or 'PIPBM', to external entities, such as manufacturers of vaccines. The results of molecular analyses and tests on IVPP are recorded in the IVTM. The IVTM helps increase the transparency of GISRS's work with IVPP– a key principle of the Framework.

The PIP Framework contributes to resilient communities in two ways: (a) by increasing the equity of access by all countries in need to pandemic response supplies such as antivirals and vaccines; and (b) by strengthening preparedness capacities in countries where they are weak.

From 2014-2017, WHO invested US$ 64M of the Partnership Contribution to support 72 countries to improve their pandemic influenza preparedness capacities. Some examples of the success include: (a) 35 countries are now able to detect unusual respiratory disease events: this represents a five-fold increase from seven countries in 2014; (b) 34 countries have functioning inpatient influenza surveillance: this doubled from 16 countries in 2014; (c) 29 countries have a human-animal interagency coordination mechanism: four-times more than in 2014; (d) 8 countries estimated the influenza disease burden, of which three have published their findings in peer-review journals; and (e) the world's first vaccine deployment simulation portal 'PIP Deploy' was launched.

Ultimately, improving public health systems and capacities provides for more resilient communities.

Source: Contribution from the WHO.

Development cooperation can build capacity in new technologies with potential to increase the resilience of communities (See Box 25 for example on the area of sustainable energy). Statistics on official development assistance (ODA) do not track the amount of bilateral assistance targeting specifically resilience, but the amount of ODA for economic infrastructure, which contributes to the provision of goods and services and ultimately with resilience of economies and communities, has increased from USD 8 billion in 2000 to USD 22 billion in 2016.[262] International collaboration also takes the form of supporting the intergovernmental process for disaster risk reduction and resilience building (see Box 26).

Box 25. Example of development cooperation in technology building resilient communities

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

Source: Contribution from the Government of Germany.

Box 26. Japan's International Cooperation on disaster risk reduction and resilience building

Japan has suffered from various disasters, including earthquakes, volcanic eruptions, floods, landslides, tsunamis and others. Through the Disaster Management Bureau of the Cabinet Office of Japan, the country took an active role in international cooperation for disaster risk reduction at the World Conference on Natural Disaster Reduction in Yokohama, Japan in 1994, the World Conference on Disaster Reduction in Kobe, Japan in 2005. The bureau also took a key role to host the Third UN World Conference on Disaster Risk Reduction (WCDRR), which was held in Sendai City, Miyagi Prefecture, in March 2015. At the WCDRR, the Government of Japan advocated the importance of mainstreaming disaster risk reduction. The Cabinet office encouraged and supported the International Consortium on Landslides (ICL) to propose the ISDR-ICL Sendai Partnerships 2015–2025 as a voluntary commitment to the WCDRR.

Source: Saya, S. (2017) Cabinet Office, Government of Japan (CAO)—Japan's International Cooperation on DRR: Mainstreaming DRR in International Societies. In: Sassa K., Mikoš M., Yin Y. (eds) *Advancing Culture of Living with Landslides*. WLF 2017. Springer.

In the United Nations system, several agencies, such as WHO[263] and WMO[264] mentioned above, have programmes to promote STI solutions that contribute directly to building resilient communities. 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 (ESCAP) has a programme on ICT and disaster risk reduction covering resilience building, monitoring drought from space, regional cooperation on space applications, and space and geographic information system (GIS) for disaster management.[265] The Drought Mechanism is a good example of regional cooperation, providing timely and free access to space-based data, products and services to participating countries,

[262] Source: OECD Data website. For more information, see: https://data.oecd.org/oda
[263] For more information, see: https://www.who.int/risk-communication/en/
[264] For more information, see: https://www.wmo.int/pages/prog/www/DPFSERA/EmergencyResp.html
[265] For more information, see: https://www.unescap.org/our-work/ict-disaster-risk-reduction

who also receive training and other capacity-building support. The Economic and Social Commission for Western Asia (ESCWA) has promoted resilience building by assisting the development of national digital transformation strategies, including addressing the links between ICT and governance and conflict prevention.[266] At the community level, member of the United Nations Country Teams (e.g. UNDP, UNICEF and WFP) have used market-ready new technologies to implement early-warning and preparedness systems, develop national capacities to manage disaster risk, vulnerability analysis and mapping, and support to social protection systems.[267]

The focal point in the United Nations system for the coordination of disaster reduction is the United Nations Office for Disaster Risk Reduction (UNISDR). It ensures synergies among the disaster reduction activities and activities in socio-economic 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. UNISDR maintains the *PreventionWeb*,[268] an online knowledge platform for disaster risk reduction, and it also develops products such as the Global Assessment Report (GAR) through partnerships with the science, civil society and private sector communities.

The UNISDR Science and Technology Conference, held in January 2016 in Geneva, resulted in the 'Science and Technology Roadmap to Support the Implementation of the Sendai Framework for Disaster Risk Reduction 2015-2030'. The Roadmap includes expected outcomes, actions, and deliverables under each of the priority of actions of the Sendai Framework (Box 27). There are also several cross-cutting actions like capacity development, gender equity, citizen engagement, public-private sector partnership, and coherence or alignment with other post-2015 global agenda like Sustainable Development Goals and climate change convention which will need to be linked with other stakeholders' actions in the implementation of the Sendai Framework.

Box 27. Summary of expected outcome of the Science and Technology Roadmap 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 risks 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 policy-makers 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 a stronger involvement and use of science to inform policy- 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

[266] For more information, see: https://www.unescwa.org/our-work/governance-and-conflict-issues
[267] For example, see: http://www1.wfp.org/resilience-building
[268] For more information, see: https://www.preventionweb.net/english/

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 policy- 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 impact on the most vulnerable communities and locations.

Source: UNISDR (2016). Science and Technology Roadmap to Support the Implementation of the Sendai Framework for Disaster Risk Reduction 2015-2030.

IX. Policy considerations

This final section summarises some key points from the paper and discusses implications for national government policies and the CSTD.

A. STI for building resilient communities

Science, technology and innovation 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.

Knowledge on resilience: Governments and relevant stakeholders are encouraged to strengthen research programs 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 stakeholder 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, often this knowledge is fragmented, and there is the need to promote and implement participatory research methods, interdisciplinary and transdisciplinary scientific collaboration for increasing understanding of community resilience considering integrated disaster reduction and sustainable transformations.

Indigenous knowledge: Traditional, local and Indigenous knowledge have been used effectively in reducing the risk of disasters and in supporting livelihoods. Harnessing this 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 use them systematically in scientific research focusing on community resilience.

Inclusive technologies: STI solutions for building community resilience should be inclusive, engaging the participation 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 ICTs and electricity, with a specific emphasis on ensuring affordable access and overcoming geographical, gender, generational, and income digital divides.

Natural hazards triggering technological disasters: With the complex nature of disasters, there is a need to promote the reduction of the risk of natural hazards triggering technological disasters (NATECH). It is important to develop an analytical framework to incorporate NATECH risks into consideration when considering strategies for building resilient communities.

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

Linkages among stakeholders: There should be an open dialogue on resilience between scientific 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 science, technology and innovation policies that contribute to building resilient communities, including through support to strategies and mechanisms that create the 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, 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 more effective use of STI for resilience. This would integrate the wide range of knowledge and expertise available within the national science and technology community into national platform activities, where community leaders, policymakers and practitioners may indicate their specific needs regarding STI for resilience.

B. 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 the ubiquity and low-cost sensors, together with improved methods for data storage, retrieval and processing. The active involvement of citizen scientists through the life-cycle of an operational research or aid project can enhance local uptake, support local diagnostics, and increase decision capacity.

Embedding into science policies: Citizen science initiatives should be promoted; building capacity of communities and citizens to collect, use and analyze data, and through budget allocation, program/project planning and execution, and dissemination of citizen science outcomes in global forums. Citizen science should be embedded in the routine way that science is conducted to support the policymaking process.

Data privacy and sharing: All stakeholders should promote the sensible use of GIS data acquired as part of citizen science initiatives in developing countries and act to protect citizens’ privacy. Taking that into consideration, they should also promote the establishment of platforms for coordination and compilation of data collected in citizen science projects to be available for use in other development-related initiatives.

Linkages with SDGs: Establish and address tangible, executable linkages, programmes and projects between citizen science and the SDGs, including those related to building resilience; especially in line with priorities of vulnerable communities.

C. International cooperation

Capacity development: The international community, including CSTD, needs to continue investing in STI for resilience and citizen science in strengthening the human and social capital, building upon what communities have already achieved as baseline and sustaining the work of community leaders, managers and champions on the ground; and ensuring documentation of these community-based level work so that these are published and available in the public domain to facilitate community learning in other settings.

Inclusive participation: the CSTD should guide the global community to adopt policies and strategies that encourage women and the youth to participate in innovation approaches towards resilience, including through citizen science.

International partnerships: The international community, including CSTD, 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.

Sharing experience: There is the need to actively promote various types of effective STI for resilient communities, sharing practical and advanced STI-based resilience experiences, cases, and successful paradigms by various forms of international collaboration and exchange activities. This platform could be utilized both at national and international level respectively by CSTD member countries and the international community in national and transnational crises.

Call for action: 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 transformations to advance the implementation of the Sendai Framework and the 2030 Agenda for Sustainable Development and the achievement of the SDGs.

X. Questions for discussion

The following are some discussion questions to further the dialogue related to the role of science, technology and innovation in building resilient communities, including through the contribution of citizen science.

A. Good practices and lessons learnt on STI for community resilience

- Can you give examples of projects/policies in your country aimed at using science, technology and innovation (STI) to build resilient communities?
- What are the main challenges confronted while trying to implement these projects/policies in your country or region?
- What are the opportunities and challenges in research and innovation for building resilient communities?
- What type of competencies are needed at national and local levels to use, adopt, adapt and maintain STI solutions for community resilience?
- What is the role of the private sector and civil society in using STI for building resilient communities?
- What have been the most effective policy instruments and policy mixes supporting research, innovation and wider diffusion of technology for community resilience?
- How to coordinate the STI policy with disaster risk reduction, health emergency and other relevant sectoral policies to provide more effective support?

B. The role of citizen science for building community resilience

- Can you provide examples of policies/projects/initiatives aimed at using/promoting citizen science to build resilient communities?
- Do these projects incorporate a gender approach?
- What are the main challenges confronted in implementing these projects?
- How new technologies (e.g. ICTs, AI, drones, big data, internet of things) are facilitating or could facilitate citizen science for resilience building?
- What are the main barriers (e.g. technical, regulation, and cultural) for implementation and scaling up?
- Which policies are needed to address these barriers, with a focus on developing country context?

C. The role of international and inter-regional collaboration on STI for community resilience

- What has been your experience in international and inter-regional collaboration in the area of STI for community resilience?
- Could you give concrete examples of effective mechanisms of collaboration?
- What could be new mechanisms and areas of collaboration (including public-private partnerships) to scale up innovations for community resilience?
- What are the actions that the international community, including the CSTD, can take to leverage the potential of STI in building resilient societies, including through the contribution of citizen science?

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