CHAPTER 7

Food Security Under a Changing Climate: Exploring the Integration of Resilience in Research and Practice

Alessandro De Pinto, Md Mofakkarul Islam, and Pamela Katic

Introduction

Climate change already affects vulnerable populations in many low- and middle-income countries and is expected to alter the lives of many more people in even more areas of the world in the future (IPCC, 2018). The nutritional status of these people is of particular importance because climate change will exacerbate the incidence of malnutrition in these

A. De Pinto (✉) · M. M. Islam · P. Katic
Natural Resources Institute, University of Greenwich, London, UK
e-mail: A.DePinto@greenwich.ac.uk

M. M. Islam
e-mail: M.M.Islam@greenwich.ac.uk

P. Katic
e-mail: P.G.Katic@greenwich.ac.uk

C. Béné and S. Devereux (eds.), *Resilience and Food Security in a Food Systems Context*, Palgrave Studies in Agricultural Economics and Food Policy, https://doi.org/10.1007/978-3-031-23535-1_7

areas (Fanzo et al., 2018; Myers et al., 2017; Phalkey et al., 2015). Some projections show an increase of 4.8 million undernourished children worldwide by 2050 due to climate change, and 97% of the people at risk of hunger will be in low-income countries (IFPRI, 2017). Climate change has a direct influence on food availability because it affects habitats and crop productivity. Furthermore, ensuing increases in prices are expected to reduce accessibility to healthy foods such as vegetables, fruits, and animal-source foods with repercussions on people's diets (Springmann et al., 2016; Wiebe et al., 2015). Despite the uncertainty in these projections, regional differences in agricultural production are expected to widen the gap between the rich and the poor (Nelson et al., 2010; Parry et al., 2004; Stevanovic et al., 2016). Trade (including food aid) might not be able to fully buffer localized food shortages and ease these problems (Elbehri et al., 2015; Nelson et al., 2009; Stevanovic et al., 2016).

Climate change will not only affect food production and sourcing; its effects are expected to ripple throughout value chains and food systems. Studies indicate that higher temperatures and prolonged exposure to high levels of CO_2 concentration could lead to losses in nutrient content (e.g., zinc, iron, proteins) of key food crops, induce changes in important quality parameters (e.g., dry matter, sugar content, citric and malic acid, organic acids, antioxidant compounds) (Dong et al., 2018; Högy & Fangmeier, 2009; Moretti et al., 2010; Myers et al., 2014), and increase the incidence of foodborne pathogens and mycotoxins (Battilani et al., 2016; Tirado et al., 2010). Storage, marketing, and retail systems will need to adapt as areas become hotter and transportation will have to negotiate with less durable and more frequently flooded roads as well as damaged port infrastructure (Nicholls & Cazenave, 2010; Shi et al., 2015). Electrical grid failures caused by hydroelectric dams that run dry or by an overburdening demand will affect retail shops as well as consumers (Portier et al., 2013). The utilization of food will also be affected. Studies suggest that increased contamination of drinking water supplies and increases in the prevalence of respiratory diseases and diarrhoea are possible, particularly in semiarid areas (Signorelli et al., 2016).

Concerns for vulnerable populations have increased not only because of the likely impact of climate change and a better understanding of the long-lasting implications of malnutrition (Alderman et al., 2006; Martins et al., 2011), but also because researchers, practitioners, and development agencies have developed a greater appreciation for the complexities of the issues surrounding food security. For example, discussions about food security immediately after World War II were mostly related to commodity trade, tariffs, barriers, food processing, and calorie availability with little primary concern regarding malnutrition (FAO, 1946). By the beginning of the 1980s, new and richer ideas had entered into the debate. Notably, Amartya Sen pointed out how, during twentieth-century famines, it was not the lack of food (total calories output from agriculture) that caused problems of hunger, but rather the inability of the poor to access it. Today, there are numerous definitions of food security, but most recent ones share common traits and describe it as a multifaceted problem linked to the availability, accessibility, utilization, and stability of food over time that affects people's physical, social and economic development (see Mark Constas' Chapter 5 in this volume). These multidimensional definitions are better suited to comprehend and address the complexity of the threats posed by climate change.

Given the magnitude and the broad reach of the challenges that the world is facing, it is not surprising that the scope of development interventions has broadened from food production to integrated approaches that target entire food systems (FAO-WHO, 2014; Mbow et al., 2019; Oliver et al., 2018). One obvious consequence of this new paradigm is that interventions require approaches of increasing complexity and collaboration among experts from different fields.

A relatively new concept supporting contemporary development thinking and interventions in climate change, humanitarian, and food security contexts is that of resilience. Resilience is now regularly used in the academic literature and within the international development community as an approach to deal with adverse shocks and to promote sustainable development (Serfilippi & Ramnath, 2018). Prosperi et al. (2016) and Vonthron et al. (2016) note that research on resilience and vulnerability could provide support when framing the principles of sustainable food systems and that the concept of resilience can be useful to rethink food emergencies and development. Because it is integrative by construction, resilience has been recognized to link together research areas that have often been considered in isolation (e.g., gender, social protection, health and nutrition, climate change, energy, infrastructure) (Béné et al., 2016), and it is expected to provide support for a systems approach with recognition for the relations among human capabilities and natural systems (Xu et al., 2015). Given the multifaceted impacts of climate change that can affect virtually all dimensions of food security, resilience has the potential to be a useful concept to help develop a coherent and inclusive method to support decision-making and plan for interventions that require work at the intersection of multiple disciplines (Grafton et al., 2019; Quandt et al., 2017; Wilson, 2010).

In this chapter, we explore how the concept of resilience has been integrated into the work on climate change and food security and whether its use has helped researchers and practitioners advance their agenda. First, we review the academic literature to determine how academics have engaged with the concept of climate resilience in a food security context. Then, we provide a case study of the way resilience is used by implementers on the ground. Finally, we draw key conclusions and suggestions on how to move the climate resilience agenda for improved food security forward.

Resilience in the Academic Literature on Food Security and Climate Change

Two parallel processes should be considered when analysing the influence of resilience on the work on climate change and food security. First, during the last two decades, published research became increasingly receptive of the progress made in the field of food security research and broadened its scope from a distinct focus on agricultural production and agricultural policies (Nelson et al., 2009, Rosegrant et al., 2014) to considering instruments associated with social inclusion and protection as well as a vision for entire food systems (Nelson et al., 2018; Rosenzweig et al., 2020; Schwan & Yu, 2018). Second, at approximately the same time, the interpretation and use of the concept of resilience went through changes that made it more usable for researchers and practitioners. The concept evolved from one describing ecosystem stability (Holling, 1973) to one illustrating the ability of social systems to absorb shocks and stressors and, through adaptive processes, to reorganize into fully functioning entities. This conceptual broadening is also how resilience became a prominent concept in the literature on food security and disaster and risk management during the first decade of the twenty-first century (Alinovi et al., 2008; Pingali et al., 2005). Furthermore, after an initial focus on resilience as an end in itself and the ensuing efforts to quantify and measure it, researchers moved to an interpretation of resilience as a means to achieving an ultimate end such as food security (Ansah et al., 2019).

A search in the Web of Science Core Collection shows that researchers working on climate change have steadily and increasingly included the concept of resilience in their work. The search of the published literature reveals that the words 'climate change' and 'resilience' appeared together in the published literature a total of 48 times during the period 1996–2000 and 8,626 times during the period 2016–2020 (Fig. 7.1).

A similar pattern is apparent when a comparable search is carried out for articles in which the words 'food security' and 'resilience' or 'climate change', 'food security', and 'resilience' appear together. In all combinations, the incidence of the word 'resilience' increases significantly after the year 2005 and even more pronouncedly after 2015 (Fig. 7.1).

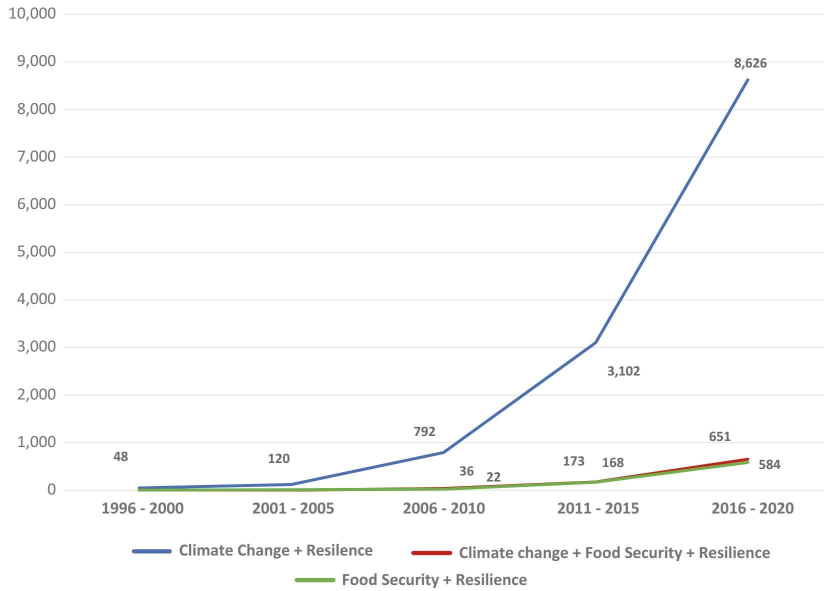

Fig. 7.1 Incidence of the words 'climate change and resilience'; 'food security and resilience'; 'climate change, food security and resilience' in selected academic literature, years 1996–2020[1] (*Note* [1]Search strings used in the Web of Science Core Collection literature search: TS = [climate change] AND TS = [resilience]; TS = [food security or food insecurity] AND TS = [resilience]; TS = [climate change] AND S = [Food Security or Food Insecurity] AND TS = [Resilience]. *Source* Authors)

What follows is a brief review of selected research at the nexus of climate change, resilience, and food security. This review reveals the wide range of responses covering all the major components of food systems that have been investigated and the wealth of information on actions and interventions that have the potential to increase people's resilience to climate shocks and stressors and improve people's food security under a changing climate.

Agricultural Food Production

While discussions on agricultural risk management have overwhelmingly concentrated on the use of crop insurance and index-based insurance (Cole et al., 2013; Giné & Yang, 2009; Giné et al., 2008; Hill et al., 2016, 2019), a range of viable strategies beyond financial instruments are available to lower climate-related risks by reducing vulnerability or by making food production systems better able to cope with and recover from shocks (Hallegatte et al., 2017; Lipper et al., 2018). Improved agricultural and pest management practices have also been widely demonstrated to have positive impacts on crop production (Arefi et al., 2017; Deb et al., 2018; Garnett et al., 2013; Midega et al., 2018). They are expected to increase and stabilize yields in the face of long-term changes in temperature, precipitation, and of the frequency and severity of extreme weather events (De Pinto, Cenacchi et al., 2020; Rosegrant et al., 2014). Gains in productivity and reductions in yield volatility are possible in both rainfed and irrigated systems through the expansion of soil and water management practices that increase water availability for crops in rainfed systems (Rockström & Barron, 2007) and the introduction of water-saving technologies in irrigated systems (Molden et al., 2010). Increasing the availability of diverse genetic material (FAO, 2011), advances in crop breeding and new genome editing systems such as CRISPR/Cas (Mojica et al., 2009) can protect crop production from a deteriorating climate (Rosegrant et al., 2014). A closer integration of crops, trees, and livestock into more complex systems is expected to stabilize or increase productivity and protect agricultural production from extreme weather events (Altieri et al., 2015; Asfaw et al., 2019; Lin, 2011; Weindl et al., 2015) and to increase the resilience of agricultural livelihoods (Quandt et al., 2017). Climate-related advisory services are considered essential to protect production and reduce output volatility by facilitating preparedness and timely responses (Aker & Mbiti, 2010; Goddard, 2016; Schimmelpfennig, 2016; Woodfine, 2009).

Distribution, Processing, and Marketing

Investment in processor and distributor networks can make supply chains less vulnerable to climate change and better suited to withstand shocks from extreme weather events (Zilberman et al., 2012). Innovations in packaging, processing, and storage practices improve efficiency, reduce waste, and increase the availability of nutritious albeit perishable foods (James & James, 2010). Expanding rural electrification is expected to increase the availability and reduce the cost of nutrient-rich, highly perishable foods such as vegetables and fruits, not only by facilitating their production using irrigation, but also by providing more cold-storage options (Arndt, 2019). Investments in processing and cold-storage facilities, feeder roads, and cooled transportation have the additional benefit of smoothing income shocks that small producers face from seasonality, market volatility, and weather shocks (da Silva & Fan, 2017). Risks of food poisoning and food spoilage can be abated with the development of quality assurance and control tools and methods that prevent or control microbiological risks (Jacxsens et al., 2010; Tirado et al., 2010). Processing foods (e.g., drying and salting meat and fish, processing milk into yogurt and cheese) is shown to reduce the need for cold storage and prevent the spoilage of nutritious foods, thus increasing its availability to consumers (Berlin et al., 2008; GLOPAN, 2016).

The general consensus in the literature is that trade will play an important role in adjusting to the shifts in agricultural and food production patterns resulting from climate change (Brenton et al., 2022; Nelson et al., 2009, 2010), improving household food access by moderating price increases, and reducing shocks to food availability (Brown & Kshirsagar, 2015; Brown et al., 2017; Lybbert & Sumner, 2012). However, in order to ensure that the stabilizing power of trade is realized, investments in maintaining, expanding, and climate-proofing existing infrastructure are considered necessary, particularly in order to reach geographically isolated, poor, and/or socially marginalized communities (Thacker et al., 2019).

Food Preparation and Consumption

The consequences of hunger and malnutrition on people's health greatly affect already vulnerable people's capacity to respond, cope, and adapt to the negative consequences of climate change (Tirado et al., 2015; Wheeler & von Braun, 2013). Addressing undernutrition and micronutrient deficiencies under a changing climate requires that micronutrient-rich foods such as vegetables, fruits, nuts, seeds, and pulses are made widely available and affordable despite unfavourable production conditions (Headey et al., 2018; Nelson et al., 2018; Ruel et al., 2017). Efforts to develop fortified food, biofortified crop varieties, and the supplementation of targeted micronutrients can help reduce people's nutritional deficiencies (Chakrabarti et al., 2018; Martorell et al., 2015) and mitigate the reduced nutrient quality in crops caused by climate change (Beach et al., 2019). In low-income countries, food processing and preservation techniques can increase food safety and preserve nutritional value of foods while minimizing the need for cold storage (FAO, 2016). Communication and participatory approaches are essential in both rural and urban settings to change consumers' behaviour and promote a dietary shift from carbohydrate-rich staples to a more diverse and healthier diet that addresses micronutrient deficiencies (Leroy & Frongillo, 2007; Ruel, 2001; Ruel et al., 2017). Nutrition labelling, advertising restrictions, taxes on unhealthy foods such as sugar-rich sodas, and nutrition education in schools and health centres are suggested policy levers that can be used to encourage behaviour change that favours resilience to climate change (Fanzo et al., 2018; Hawkes et al., 2017).

Capacity Building in Institutions and Governance

The role of national and regional governments, community organizations, and market institutions is now recognized as essential to provide information and encourage the types of innovation and investments necessary to manage climate risks (Meinzen-Dick et al., 2013). In particular, investments in improving governments and local organizations' capacities to provide effective leadership are considered necessary for the coordination of responses that span across numerous stakeholders and economic sectors (Babu et al., 2019). Many new technologies that are expected to improve people and systems' resilience require that coherent policies and regulatory procedures be in place (England et al., 2018; Saito, 2013) and that at times, these must be globally harmonized (such as in the case of genetic engineering) to avoid trade bans and implementation bottlenecks (Duensing et al., 2018).

Informal institutions, for example social networks, are recognized to promote cooperation in resource management and income diversification, and thereby contribute to livelihood and ecological resilience (Kristjanson et al., 2017). They can also help reduce the gender gap in information about climate risks and in decision-making power which are recognized as detrimental to develop efficient responses to climate change and to achieve better nutrition and health outcomes (Bryan et al., 2017; De Pinto, Seymour et al., 2020; Peterman et al., 2014). Stronger governance is essential to reduce investment gaps that penalize vulnerable groups and to ensure that resilience-enhancing investments are spread across economic, social, and environmental dimensions (McGregor et al., 2020; Meinzen-Dick et al., 2013).

An Operational Problem

Notwithstanding the breadth and depth of the research at the nexus of climate change, food security, and resilience, our review reveals some of its limits. We found that, overwhelmingly, studies use the word 'resilience' to give an intuitive depiction of a desirable trait of food systems, without connecting it with a specific theory or framework to back up their claims about increasing the resilience of households or communities to climate stresses or shocks. We also found that despite the complexity of the system analysed, the characterization of resilience (resilience of what and to what) often lacks specificity. Only a small portion of the literature actually attempts to model or measure resilience or how resilience contributes to food security (Bene et al., 2017). Furthermore, most studies linking resilience and food security track multiple commonly available production-oriented proxies (e.g., yields, production, and revenues) but very few consider multiyear resilience-related outcomes. These observations mirror what other authors have found in their reviews of the literature. Hogeboom et al. review the nexus water, energy, and food (Hogeboom et al., 2021) and find that only a few studies model (20%) or measure (13%) resilience. In a thorough analysis of papers that look at resilience in agri-food supply chains, Stone and Rahimifard (2018) find that there is a poor consensus on what elements are the most important for resilience. Ansah et al. (2019) suggest that since studies do not resort to a common resilience framework, the number of different indicators used, the length of time that they were tracked, the different units of analysis, and the different approaches (statistical vs modelling) all make comparing the results difficult, if possible at all. Constas et al. (2014) note how variable selection tends to be context-specific and driven by data availability rather than theory.

Operational issues might be at the root of these shortcomings. Largely guided by the work of the WFP/FAO 'Resilience Measurement Technical Working Group', important conceptual progress has been made in the measurement of resilience in the context of food security and humanitarian interventions (Constas et al., 2014). Efforts to increase the operational viability of the concept of resilience can be found in studies that attempt to connect more formally agricultural and household activities with resilience and human well-being (for example, Quandt et al., 2019; Robinson et al., 2015; Rockström, 2003; Silici et al., 2011; Verchot et al., 2007). However, despite these valuable contributions, difficulties remain in connecting concepts that are both intuitive and complex. This is in part due to the structural complexities of working with systems made of many interconnected parts in which a shock affects the functioning or behaviour of one component of the system or of a group of people and then ripples through the system to reach other components or groups of individuals (Béné, 2020). Predicting the effects of investments and interventions that aim to abate the negative effects of climate change is also difficult because of positive and negative feedback loops (Bryan et al., 2017), non-linear relationships among factors that determine the system functioning, and because of the existence of thresholds below which a change in one component does not result in some appreciable difference in the performance of the whole system (Levine, 2014).

These conceptual difficulties might also explain why the literature provides limited evidence on the causal relationship between actions that purportedly increase resilience to climate stresses and shocks and improved food security. For example, Wilson (2010) points to the limits of multifunctional agricultural systems in building resilience while Cochrane and Cafer (2018) find limits and exceptions to the expected positive effect of diversification in agricultural livelihoods and smallholder production on community resilience. Gil et al. (2017) review the literature on integrated farming systems and find that studies generally claim a positive association between integrated farm systems and enhanced resilience (by virtue of increased yields, reduced yield variance, or increased incomes), but they also stress that very few studies identify the causal pathways that lead to increased climate resilience. Rosenstock et al. (2019), perform an extensive review of the published literature on climate smart agriculture (CSA), an approach to agriculture that includes among its objectives improving resilience, and find that less than a fifth of all articles attempt to connect CSA practices with resilience. They find that most of the articles that do so focus on a few indicators (e.g., soil quality and input-use efficiency) and assume that improvements in these indicators signify an increased resilience to climate change. The authors also state that the general disagreement among researchers on what to measure and what indicators to use, might explain why the literature on CSA provides so little information on one of its foundational pillars. The few cases where resilience per se has been measured directly are through a self-assessed recovery index, estimated through series of recall questions and psychometric techniques (Béné & Haque, 2021). However, these tools have been developed to analyse resilience at the household level rather than at a broader food system level.

Therefore, it appears that despite the amount of research on how to respond to various climate threats, our knowledge of how these actions translate into resilience is still limited, and an identification of a sequence of investments that can generate climate-resilient pathways to food security still appears elusive.

Resilience in Practice—The Case of Projects Implemented Through the Adaptation Fund (AF)

The international development community has embraced the concept of resilience as a proxy for long-term growth, with a clear recognition that resilience to stressors and adverse shocks is essential for individuals and communities to achieve sustainable development. As a result, the role of resilience is codified in several targets of the United Nations' 2015 Sustainable Development Goals (e.g., SDG targets 1.5, 2.4, 13.1). In order to understand how, up to now, practitioners on the ground have engaged with the concept of resilience in a climate change and food security context, we analysed a series of projects which were implemented through the Adaptation Fund (AF). The AF was chosen for two reasons. Firstly, the AF was created specifically to finance adaptation projects in low- and middle-income countries that are parties to the Kyoto Protocol and are particularly vulnerable to the adverse effects of climate change

(Adaptation Fund, 2021a), and secondly, agriculture and food security are two of the key areas in which the AF provides support (Adaptation Fund, 2021b).

As of April 2021, the AF had financed over 160 projects since its inception in 2010 (Adaptation Fund, 2021c). Of these, we selected twelve projects (Table 7.1) for in-depth analysis based on the following criteria: (i) the projects had to have a strong 'food security' component, (ii) they had to have 'resilience' building as a key objective, and (iii) they had to be at the implementation stage or completed. We selected cases from diverse countries and regions to account for variations in climatic, ecological, and socioeconomic contexts. We excluded projects that were in high-income countries (e.g., Moldova), funded primarily for readiness building of recipients, or were of very short duration, e.g., one year or less.

Within each project, we explored: (i) whether resilience was conceptualized as a means to achieving food security and/or other developmental outcomes or was conceptualized as an end in itself; (ii) whether a characterization of resilience (resilience of what and to what) was provided; (iii) the type of interventions proposed for enhancing resilience; and (iv) what indicators and methods were used to evaluate whether resilience was achieved. From a methodological viewpoint, our approach is 'descriptive-exploratory' in nature and uses 'typical' or 'illustrative' cases (Yin, 2009).

With few exceptions (e.g., PN10), the projects we analysed commonly framed resilience as an 'end' goal for the project. However, only two projects (PN7 and PN8) provided a formal definition of resilience. In all the projects, the term was often framed in contrast to the 'vulnerability' of certain entities against various climate changes and stresses. This narrative indicates that resilience was considered as an 'antidote' to vulnerability. Another term, 'adaptive capacity', which was conceptualized as a mediatory variable between vulnerability and resilience, was commonly found. The implicit Theory of Change (ToC) common to all those projects implied that certain interventions would increase the adaptive capacity of vulnerable entities, reduce loss and damages, and eventually reduce vulnerability, which, in turn, would improve resilience (as an end-goal) (Fig. 7.2).

Depending on the project, the targeted beneficiaries included smallholder farmers, farm households, agropastoralists, rural communities, small pond-based aquaculture systems, agricultural sector, livestock systems, or even 'natural systems' such as forests (Fig. 7.2). Project narratives about specific entities of interest were not obvious and often involved

Table 7.1 Case study projects

Code	*Project title*	*Sector*	*Country*	*Start date*	*Duration*
PN1	Agricultural Climate Resilience Enhancement Initiative (ACREI)	Food Security	Ethiopia, Kenya, Uganda	30/08/2018	3 years
PN2	Building Adaptive Capacities of Small Inland Fishermen Community for Climate Resilience and Livelihood Security, Madhya Pradesh, India	Food Security	India	18/11/2018	3 years
PN3	Reducing the Vulnerability by Focusing on Critical Sectors (Agriculture, Water Resources and Coastlines) in order to Reduce the Negative Impacts of Climate Change and Improve the Resilience of these Sectors	Multisector	Costa Rica	10/07/2015	5 years
PN4	Enhancing Adaptive Capacity and Increasing Resilience of Small and Marginal Farmers in Purulia and Bankura Districts of West Bengal	Agriculture	India	28/05/2015	4 years
PN5	Enhancing the Resilience of the Agricultural Sector and Coastal Areas to Protect Livelihoods and Improve Food Security	Multisector	Jamaica	02/11/2012	3.5 years

(continued)

Table 7.1 (continued)

Code	*Project title*	*Sector*	*Country*	*Start date*	*Duration*
PN6	Enhancing Climate Resilience of Rural Communities Living in Protected Areas of Cambodia	Ecosystem-based Adaptation	Cambodia	21/05/2013	5 years
PN7	Building resilience to climate change and variability in vulnerable smallholders	Agriculture	Uruguay	22/10/2012	5 years
PN8	Adapting to Climate Change Through Integrated Risk Management Strategies and Enhanced Market Opportunities for Resilient Food Security and Livelihoods	Food Security	Malawi	06/11/2020	5 years
PN9	Improving adaptive capacity of vulnerable and food-insecure populations in Lesotho	Food Security	Lesotho	10/08/2020	4 years
PN10	Adapting to climate induced threats to food production and food security in the Karnali Region of Nepal	Food Security	Nepal	10/26/2018	4 years
PN11	Enhancing Resilience of Communities to the Adverse Effects of Climate Change on Food Security in Mauritania	Food Security	Mauritania	08/14/2014	4 years
PN12	Building Resilient Food Security Systems to Benefit the Southern Egypt Region (Phase-I)	Food Security	Egypt	03/31/2013	4 years

Source Compiled by the authors

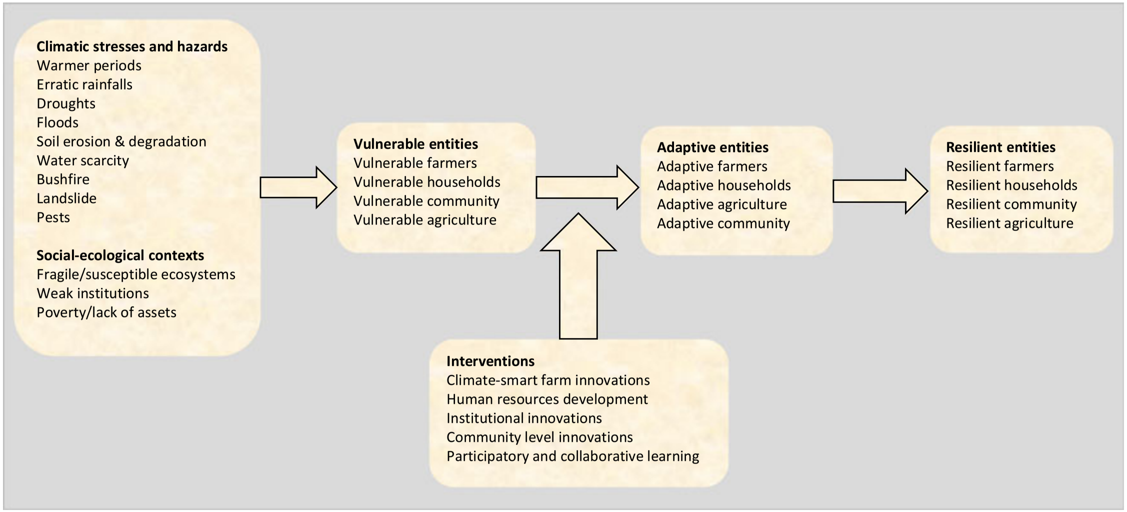

Fig. 7.2 The generic resilience intervention framework/compiled from the case study projects (*Source* Authors)

an overlap of these various entities, with some projects specifying one entity (PN2, PN11) and others (e.g., PN1, PN6, PN10) referring to the resilience of multiple entities.

Climate-induced 'variability' and 'extremes' were common vulnerability factors and differed from country to country. The most common concerns were erratic rainfall, unpredictable monsoon season, high temperature, dry spells, droughts, and floods. Some other climate-induced biotic and abiotic stresses were also mentioned including water shortages, soil fertility loss, agricultural drainage issues, landslides, soil erosion, pest infestations, deforestation, and bushfires. These shocks and stresses were said to lead to yield/productivity decline, loss of income, loss of livelihood, and reduced food security. References to specific properties of related ecosystems were provided in some cases. Examples include: desert or arid ecosystems, special protected areas with valuable biodiversity, and fragile mountain ecosystems and grasslands (pasturelands). Vulnerability framing however was not limited to climatic reasons. Low income or poverty, discriminatory socio-cultural norms of exclusion (e.g., women, youth, and ethnic minority groups), lack of institutional capacities and services as well as inadequate awareness and knowledge of various actors regarding climatic change and appropriate adaptation options were argued to be key reasons for vulnerability.

The proposed interventions varied widely, with a common one being the promotion of new and improved agricultural technologies and practices. This included intensification and diversification of crop and animal species; crop rotations; Integrated Pest Management (IPM); better water management practices (e.g., polytunnels, microdams, irrigation schemes, rainwater harvesting, water mills, and drip irrigation systems), soil conservation (e.g., planting legumes and soil conservation practices); new planting time and techniques; agroforestry (e.g., planting native, fast-growing, and multipurpose perennials and/or tree species that provide food, fuel, timber, and other ecosystem services); conservation agriculture practices (e.g., minimum tillage and retention of crop residues); agricultural flood control techniques (e.g., semi-circular bunds, check dams, gully plugs, infiltration ditches, swales, and agroforestry plantations); drought tolerant field crops and livestock species; and integrated management of grasslands.

A few projects (e.g., PN8, PN9) mentioned risk management and market-related types of interventions such as market analysis and business plan development, contract farming, value chain development, agricultural insurance, microcredit, and new funding packages for farmers. Training of farmers about climatic changes, new agricultural practices, and new financial and market opportunities, was a common intervention.

All the projects showed a clear ambition to improve adaptive capacity at the institutional level. Enhancing the technical capacity of government and non-government institutions, especially meteorological and agricultural extension services, for monitoring local agroclimatic contexts and delivering location and weather-specific, timely, and climate-proof services (e.g., seasonal forecasts) featured prominently in all the projects. Staff training and development of new educational materials (e.g., manuals) appeared as common forms of intervention. Other interventions included: fostering learning and knowledge exchange through improved data analysis and management; communication and advocacy through short films, publications, printed materials, and press; forming new climate-smart farmer field schools or strengthening the capacity of existing ones; and demonstration plots. Engaging with and influencing policies through feedback and advocacy, and the mainstreaming of climate field schools were also among the institutional level interventions.

Interventions were targeted at the community level as well. These included: forming new resource user groups and/or strengthening the adaptive capacity of existing groups; training of local institutions (e.g., village *Panchayats* in India and *Village Development Committees* in Nepal) on climate change; developing community-based adaptation action plans; forming community grain banks, seed banks, and fodder banks; community-managed storage of agricultural produce, community forestry, and community-based drinking water and biogas facilities.

At both the household and community levels, there was a strong emphasis on creating new Income Generating Activities (IGAs) for target beneficiaries. Examples included: rabbit and duck rearing, medicinal and aromatic plants, oil extraction, organic farming for niche market, cultivation of high-value fruits and vegetables, milk processing, candle making, pickle making, growing herbs and mushrooms, and fuel-efficient cooking devices. An emphasis on women and youth was common in all these IGAs.

In all the projects, we found a strong emphasis on 'participatory learning and action' (PLA) involving project staff and beneficiaries. Almost all the projects abstained from top-down interventions and emphasized developing locally appropriate adaptation actions through participatory approaches. Consultation with stakeholders (including beneficiaries) during project preparation was a prerequisite for funding application, as evident in the Adaptation Fund project proposal template. To fulfill this requirement, the projects used a range of methods—including stakeholder meetings, workshops, interviews, focus groups, surveys, visits, and participant observations—at the proposal development stage. Some projects also conducted vulnerability assessments, or utilized past vulnerability assessment reports, and included them in the project proposals (e.g., PN2, PN4, PN9, PN10). Almost all projects emphasized learning and knowledge-sharing using a range of interventions, e.g., community radio, farmer field schools, enhancing the capacities of agricultural extension services, and continuous sharing of project results and best practices.

While all the projects explicitly stated resilience enhancement as a goal, the indicators proposed for evaluating such outcome varied widely and were questionable in some instances. The common outcome indicators proposed included: percent changes in farmers' income, percent of farmers adopting new agricultural practices, percent of the target population aware of climatic changes, decreasing livestock mortality on farms, percent of communities with better access to water, improvement in agricultural outputs, reduced incidents of downstream flooding and soil erosion; number of farmers with increased access to irrigation schemes, rainwater harvesting, and drip irrigation; number of farmers benefitting from soil conservation and land husbandry infrastructure, availability of local planning tools, percent of farmers reporting income loss and increase in supplementary income, and increased community awareness and knowledge. A number of rather vague indicators, such as 'percent of farmers with climate-resilient livelihoods', were proposed, for which no measurement methods were described. At the ecosystem level, some listed indicators were increased availability of forage and water for animals, increased native grassland biodiversity, and improvement in Vegetation Index. All these outcomes were expected to be achieved within each project's lifetime, ranging from 3 to 5 years (Table 7.1).

The outcome indicators were proposed to be evaluated based on reviews of project documents, focus groups, discussions, baseline and endline surveys, and government statistics. Of these, baseline and endline comparison through surveys was common. However, no project provided details of such evaluation methods, e.g., randomization, use of counterfactual and the associated statistical methods. Moreover, although adverse impacts of climatic changes on food security were commonly framed as a rationale for the projects, none provided any indicator or methods for assessing food security outcomes over time, which could have potentially manifested the resilience of the entities of interest in the projects.

Discussion

In this chapter, we aimed to assess how the concept of 'resilience' has been integrated into discussions about climate change and food security by both academics and practitioners. We first performed a targeted review of the academic literature on climate change, food security, and resilience. We found an overwhelming increase in the use of this concept in the literature over the last two decades, while the concept of resilience itself was going through a transformation, from describing the stability of ecological systems to embodying the adaptive and reorganizational capacity of social-ecological systems. As such, resilience has become most of all an intuitive way for researchers to describe the ability of a system to bounce back to normal functioning (or even improve) after a shock. Our review of the literature suggests that the combination of a more advanced understanding of food security coupled with the concept of resilience has given support to researchers to investigate the many aspects of food systems that are vulnerable to climate change and to find and propose solutions. This is reflected in the myriad insights that the literature offers into how to address climate threats. This wealth of knowledge gets diluted, however, in a cacophony of methods, metrics and indexes and logical leaps when it is used to connect resilience to food security more formally or empirically. It appears that the problem is not in identifying what actions can potentially improve food security but rather in determining the pathways through which such actions translate into resilience, and then into food security. The result is that the academic community is still far from having a robust method for identifying an efficient and rational sequence of interventions that improves people's food security in response to one or multiple climate threats.

At the practitioner level, our case study of twelve Adaptation Fund projects revealed that, unlike the more recent trend in the academic literature, resilience in those projects is still commonly framed as an end goal, rather than a means to achieve other outcomes. Similar to that in the academic literature, the projects refer to the resilience of a number of entities, including farmers, farm households, agricultural or natural resource systems, and agricultural sectors. Such a diverse, and often overlapping focus makes it challenging to identify appropriate resilience-building interventions and to evaluate project outcomes, since the requisite evaluation indicators are likely to vary across interventions and must be able to account for synergies and trade-offs. Such multilevel indicators were clearly missing in the Adaptation Fund projects we reviewed. The interventions for achieving resilience appear to be multifaceted and systemic in nature, combining technical interventions with institutional interventions at multiple levels, and are coupled with a strong focus on participatory learning and action. These interventions were generally in line with the theories of resilience found in the academic literature, even though their breadth falls short of what would be expected from a food systems approach—increasingly identified as crucial for food security interventions in a range of contexts. More importantly, the key limitation in the Adaptation Fund projects is in the evaluation of resilience outcomes, both in terms of appropriate indicators and methods. There is a lack of standardization of the definition and metrics of resilience that coincides with the problems described in the academic literature. It is possible that the absence of a common language and metrics for measurement we found in the literature hampers the ability of the development community to prioritize interventions and to monitor and evaluate resilience-building programmes. Although the lack of agreement on definitions and metrics may allow flexibility and strategic manoeuvring for development projects, it poses the risk of making resilience yet another buzzword in the lexicon of development.

Conclusion

Resilience appears to have contributed to what, in our opinion, is a positive shift in the paradigm underlying climate change and food security work in ways that favour integrated approaches and interventions. However, despite its appealing qualities, the operationalization of resilience in the context of climate change and food security remains problematic. It seems clear that further support is required to develop a new generation of operational definitions that harmonizes frameworks and metrics in order to create a common language to advance core ideas. This is necessary to translate high-level concepts of resilience into actionable information and to develop resilience-enhancing actions at multiple levels. Beyond the efforts of the academic community to offer practical and systematic guidance to decision-makers on how to use resilience in development work, it is important that partnerships between academic communities and practitioners are developed and strengthened to give more coherence to the formulation, implementation, and evaluation of resilience-building activities. At present, such collaborative designs and implementations are the exception rather than the norm in climate change and food security policies, projects, and programmes.

References

Adaptation Fund. (2021a). *Adaptation Fund—Governance*. https://www.adaptation-fund.org/about/governance/

Adaptation Fund. (2021b). *Adaptation Fund—Project sectors*. https://www.adaptation-fund.org/projects-programmes/project-sectors/

Adaptation Fund. (2021c). *Adaptation Fund—Projects & programmes*. https://www.adaptation-fund.org/projects-programmes/project-information/projects-table-view/

Aker, J. C., & Mbiti, I. M. (2010). Mobile phones and economic development in Africa. *Journal of Economic Perspectives, 24*(3), 207–232.

Alderman, H., Hoddinott, J., & Kinsey, B. (2006). Long term consequences of early childhood malnutrition. *Oxford Economic Papers, 58*(3), 450–474.

Alinovi, L., Mane, E., & Romano, D. (2008). Towards the measurement of household resilience to food insecurity: Applying a model to Palestinian household data. In R. Sibrian (Ed.), *Deriving food security information from national household budget surveys: Experiences, achievement, challenges* (pp. 137–152). United Nations Food and Agriculture Organization.

Altieri, M. A., Nicholls, C. L., Henao, A., & Lana, M. A. (2015). Agroecology and the design of climate change-resilient farming systems. *Agriculture and Sustainable Development, 35*, 869–890.

Ansah, I. G. K., Gardebroek, C., & Ihle, R. (2019). Resilience and household food security: A review of concepts, methodological approaches and empirical evidence. *Food Security, 11*(6), 1187–1203.

Arefi, H. I., Saffari, M., & Moradi, R. (2017). Evaluating planting date and variety management strategies for adapting winter wheat to climate change impacts in arid regions. *International Journal of Climate Change Strategies and Management, 9*(6), 846–863.

Arndt, C. (2019). Renewable energy: Bringing electricity to revitalize Africa's rural areas. In *Global food policy report 2019* (pp. 60–67). International Food Policy Research Institute.

Asfaw, M., Geta, E., & Mitiku, F. (2019). Economic efficiency of smallholder farmers in wheat production: The case of abuna Gindeberet district, Oromia national regional state, Ethiopia. *International Journal of Environmental Sciences and Natural Resource, 16*(2), 41–51.

Babu, S. C., De Pinto, A., & Paul, N. (2019). Strengthening institutional capacity for disaster management and risk reduction through climate-resilient agriculture. In V. Venkatachalam Anbumozhi, M. Breiling, & V. Reddy (Eds.), *Disasters, climate change and food security: Assessment, analysis and action for ASEAN* (pp. 269–289). Economic Research Institute for ASEAN and East Asia.

Battilani, P., Toscano, P., Van der Fels-Klerx, H. J., Moretti, A., Camardo Leggieri, M., Brera, C., Rortais, A., Goumperis, T., & Robinson, T. (2016). Aflatoxin B1 contamination in maize in Europe increases due to climate change. *Scientific Reports, 6*, 24328.

Beach, R. H., Sulser, T. B., Crimmins, A., Cenacchi, N., Cole, J., Fukagawa, N. K., Mason-D'Croz, D., Myers, M., Sarofim, S., Smith, M., & Ziska, L. H. (2019). A modeling approach combining elevated atmospheric CO_2 effects on protein, iron and zinc availability with projected climate change impacts on global diets. *The Lancet Planetary Health, 3*(7), 307–317.

Béné, C. (2020). Resilience of local food systems and links to food security—A review of some important concepts in the context of COVID-19 and other shocks. *Food Security, 12*, 805–822.

Béné, C., Arthur, R., Norbury, H., Allison, E. H., Beveridge, M. C., Bush, S., Campling, L., Leschend, W., Little, D., Squires, D., Thilsted, S. H., Troelli, M., & Williams, M. (2016). Contribution of fisheries and aquaculture to food security and poverty reduction: Assessing the current evidence. *World Development, 79*, 177–196.

Béné, C., Chowdhury, F. S., Rashid, M., Dhali, S. A., & Jahan, F. (2017). Squaring the circle: Reconciling the need for rigor with the reality on the ground in resilience impact assessment. *World Development, 97*, 212–231.

Béné, C., & Haque, M. A. B. (2021). Strengthening the resilience of vulnerable communities—Results from a quasi-experimental impact evaluation in coastal Bangladesh. *European Journal of Development Research, 34*(8). https://doi.org/10.1057/s41287-021-00399-9

Berlin, J., Sonesson, U., & Tillman, A. (2008). Product chain actors' potential for greening the product life cycle. *Journal of Industrial Ecology, 12*, 95–110.

Brenton, P., Chemutai, V., & Pangestu, M. (2022). Trade and food security in a climate change-impacted world. *Agricultural Economics, 53*, 580–591.

Brown, M. E., Carr, E. R., Grace, K. L., Wiebe, K., Funk, C. C., Attavanich, W., Backlund, P., & Buja, L. (2017). Do markets and trade help or hurt the global food system adapt to climate change? *Food Policy, 68*, 154–159.

Brown, M. E., & Kshirsagar, V. (2015). Weather and international price shocks on food prices in the developing world. *Global Environmental Change, 34*, 31–40.

Bryan, E., Theis, S., Choufani, J., De Pinto, A., Meinzen-Dick, R., & Ringler, C. (2017). Gender-sensitive, climate-smart agriculture for improved nutrition in Africa south of the Sahara. In A. De Pinto & J. M. Ulimwengu (Eds.), *A thriving agricultural sector in a changing climate: The contribution of climate-smart agriculture to Malabo and sustainable development goals* (pp. 114–135). International Food Policy Research Institute.

Chakrabarti, S., Kishore, A., Raghunathan, K., & Scott, S. P. (2018). Impact of subsidized fortified wheat on anaemia in pregnant Indian women. *Maternal & Child Nutrition, 15*(1), 12669.

Cochrane, L., & Cafer, A. (2018). Does diversification enhance community resilience? A critical perspective. *Resilience International Policies, Practices and Discourses, 6*(2), 129–143.

Cole, S., Giné, X., & Vickery, J. (2013). *How does risk management influence production decisions? Evidence from a field experiment* (Policy Research Working Paper, 6546). World Bank.

Constas, M., Frankenberger, T. R., Hoddinott, J., Mock, N., Romano, D., Béné, C., & Maxwell, D. (2014). *A common analytical model for resilience measurement—Causal framework and methodological options*. Resilience Measurement Technical Working Group (FSiN Technical Series Paper No. 2). World Food Program and Food and Agriculture Organization of the United Nations.

da Silva, G. J., & Fan, S. (2017). Smallholders and urbanization: Strengthening rural-urban linkages to end hunger and malnutrition. In *Global food policy report 2017* (pp. 14–23). International Food Policy Research Institute.

De Pinto, A., Cenacchi, N., Kwon, H.-Y., Koo, J., & Dunston, S. (2020). Climate smart agriculture and global food-crop production. *PLOS One, 15*(4), 0231764.

De Pinto, A., Seymour, G., Bryan, E., & Bhandari, P. (2020). Women's empowerment and farmland allocations in Bangladesh: Evidence of a possible pathway to crop diversification. *Climatic Change, 163*, 1025–1043.

Deb, P., Babel, M. S., & Denis, A. F. (2018). Multi-GCMs approach for assessing climate change impact on water resources in Thailand model. *Earth Systems and Environment, 4*, 825–839.

Dong, J., Gruda, N., Lam, S. K., Li, X., & Duan, Z. (2018). Effects of elevated CO_2 on nutritional quality of vegetables: A review. *Frontiers in Plant Sciences, 9*, 924.

Duensing, N., Sprink, T., Parrott, W. A., Fedorova, M., Lema, M. A., Wolt, J. D., & Bartsch, D. (2018). Novel features and considerations for ERA and regulation of crops produced by genome editing. *Frontiers in Bioengineering and Biotechnology, 6*, 79.

Elbehri, A., Elliot, J., & Wheeler, T. (2015). Climate change, food security and trade: An overview of global assessments and policy insights climate change and food systems. *Global assessments and implications for food security and trade* (pp. 1–19). Food and Agriculture Organization of the United Nations.

England, M. I., Dougill, A. J., Stringer, L. C., Vincent, K. E., Pardoe, J., Kalaba, F. K., Mkwambisi, D. D., Namaganda, E., & Afionis, S. (2018). Climate change adaptation and cross-sectoral policy coherence in southern Africa. *Regional Environmental Change, 18*, 2059–2071.

Fanzo, J., Davis, C., McLaren, R., & Choufani, J. (2018). The effect of climate change across food systems: Implications for nutrition outcomes. *Global Food Security, 18*, 12–19.

FAO. (1946). *World food survey*. Food and Agriculture Organization of the United Nations. https://www.fao.org/publications/card/en/c/cb6105en/

FAO. (2011). *Synthetic account of the second global plan of action for plant genetic resources for food and agriculture*. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/i2650e/i2650e.pdf

FAO. (2016). *The state of food and agriculture: Climate change, agriculture and food security*. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/i6030e/I6030E.pdf

FAO-WHO. (2014). *Conference outcome document: Rome declaration on nutrition*. Food and Agriculture Organization of the United Nations. https://www.fao.org/3/ml542e/ml542e.pdf

Garnett, T., Appleby, M. C., Balmford, A., Bateman, I. J., Benton, T. G., Bloomer, P., Burlingame, B., Dawkins, M., Doland, L., Fraser, D., Herrero, M., Hoffmann, I., Smith, P., Thornton, P. K., Toulmins, C., Vermeulen, S. J., & Godfray, H. C. J. (2013). Sustainable intensification in agriculture: Premises and policies. *Science, 341*(6141), 33–34.

Gil, J. D. B., Cohn, A. S., Duncan, J., Newton, P., & Vermeulen, S. (2017). The resilience of integrated agricultural systems to climate change. *Wires Climate Change, 8*, 461.

Giné, X., Townsend, R., & Vickery, J. (2008). Patterns of rainfall insurance participation in rural india. *World Bank Economic Review, 22*(3), 539–566.

Giné, X., & Yang, D. (2009). Insurance, credit, and technology adoption: Field experimental evidence from Malawi. *Journal of Development Economics, 89*(1), 1–11.

GLOPAN. (2016). *Food systems and diets: Facing the challenges of the 21st century*. Global Panel on Agriculture and Food Systems for Nutrition. http://glopan.org/sites/default/files/ForesightReport.pdf

Goddard, L. (2016). From science to service. *Science, 353*(6306), 1366–1367.

Grafton, R. Q., Doyen, L., Béné, C., Borgomeo, E., Brooks, K., Chu, L., Cumming, G. S., Dixon, J., Dovers, S., Garrick, D., & Helfgott, A. (2019). Realizing resilience for decision-making. *Nature Sustainability, 2*(10), 907–913.

Hallegatte, S., Vogt-Schilb, A., Bangalore, M., & Rozenberg, J. (2017). Unbreakable: Building the resilience of the poor in the face of natural disasters. *Climate change and development*. World Bank.

Hawkes, C., Harris, J., & Gillespie, S. (2017). Changing diets: Urbanization and the nutrition transition. *Global food policy report, 2017* (pp. 34–41). International Food Policy Research Institute.

Headey, D., Hirvonen, K., & Hoddinott, J. (2018). Animal sourced foods and child stunting. *American Journal of Agricultural Economics, 100*(5), 1302–1319.

Hill, R. V., Kumar, N., Magnan, N., Makhija, S., de Nicola, F., Spielman, D. J., & Ward, P. S. (2019). Ex ante and ex post effects of hybrid index insurance in Bangladesh. *Journal of Development Economics, 136*, 1–17.

Hill, R. V., Robles, M., & Ceballos, F. (2016). Demand for a simple weather insurance product in India: Theory and evidence. *American Journal of Agricultural Economics, 98*(4), 1250–1270.

Hogeboom, R. J., Borsje, B. W., Deribe, M. M., Van Der Meer, F. D., Mehvar, S., Meyer, M. A., Özerol, G., Hoekstra, A. Y., & Nelson, A. D. (2021). Resilience meets the water–energy–food nexus: Mapping the research landscape. *Frontiers in Environmental Science, 9*, 630395.

Högy, P., & Fangmeier, A. (2009). Atmospheric CO_2 enrichment affects potatoes: 2 tuber quality traits. *European Journal of Agronomy, 30*, 85–94.

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics, 4*, 1–23.

IFPRI. (2017). Food policy indicators: Tracking change. *Global food policy report* (pp. 84–110). International Food Policy Research Institute.

IPCC. (2018). Summary for policymakers. In V. Masson-Delmotte, P. Zhai, H. O. Portner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, & T. Waterfield (Eds.), *Global warming of 1.5 °C. An IPCC special report on the impacts of global warming of 1.5 °C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*. World Meteorological Organization.

Jacxsens, L., Luning, P. A., der Vorst, J., Devlieghere, F., Leemans, R., & Uyttendaele, M. (2010). Simulation modelling and risk assessment as tools to identify the impact of climate change on microbiological food safety—The case study of fresh produce supply chain. *Food Research International, 43*, 1925–1935.

James, S. J., & James, C. (2010). The food cold-chain and climate change. *Food Research International, 43*, 1944–1956.

Kristjanson, P., Bryan, E., Bernier, Q., Twyman, J., Meinzen-Dick, R., Kieran, C., Ringler, C., Jost, C., & Doss, C. (2017). Addressing gender in agricultural research for development in the face of a changing climate: Where are we and where should we be going? *International Journal of Agricultural Sustainability, 15*(5), 482–500.

Leroy, J. L., & Frongillo, E. A. (2007). Can interventions to promote animal production ameliorate undernutrition? *The Journal of Nutrition, 137*(10), 2311–2316.

Levine, S. (2014). *Assessing resilience: Why quantification misses the point* (HPG working paper). https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/9049.pdf

Lin, B. B. (2011). Resilience in agriculture through crop diversification: Adaptive management for environmental change. *BioScience, 61*, 183–193.

Lipper, L., McCarthy, B., Zilberman, D., Asfaw, S., & Branca, G. (Eds.). (2018). *Climate smart agriculture: Building resilience to climate change*. Food and Agriculture Organization of the United Nation.

Lybbert, T. J., & Sumner, D. A. (2012). Agricultural technologies for climate change in developing countries: Policy options for innovation and technology diffusion. *Food Policy, 37*, 114–123.

Martins, V. J., Toledo Florêncio, T. M., Grillo, L. P., do Carmo, M., Franco, P., Martins, P. A., Clemente, A. P. G., Santos, C. D. L., de Fatima, M., Vieira, A., & Sawaya, A. L. (2011). Long-lasting effects of undernutrition. *International Journal of Environmental Research and Public Health, 8*(6), 1817–1846.

Martorell, R., Ascencio, M., Tacsan, L., Alfaro, T., Young, M. F., Yaw Addo, O., Dary, O., & Flores-Ayala, R. (2015). Effectiveness evaluation of the food fortification program of Costa Rica: Impact on anemia prevalence and hemoglobin concentrations in women and children. *American Journal of Clinical Nutrition, 101*(1), 210–217.

Mbow, C., Rosenzweig, C., Barioni, L. G., Benton, T. G., Herrero, M., Krishnapillai, M., Liwenga, E., Pradhan, P., Rivera-Ferre, M. G., Sapkota, T., Tubiello, F. N., & Xu, Y. (2019). Food security. In P. R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H. O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, & J. Malley (Eds.), *Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems*. Intergovernmental Panel on Climate Change, Geneva.

McGregor, D., Whitaker, S., & Sritharan, M. (2020). Indigenous environmental justice and sustainability. *Current Opinion in Environmental Sustainability, 43*, 35–40.

Meinzen-Dick, R., Bernier, Q., & Haglund, E. (2013). *The six 'ins' of climate-smart agriculture: Inclusive institutions for information, innovation, investment, and insurance* (CAPRi working paper 114). International Food Policy Research Institute.

Midega, C. A. O., Pittchar, J. O., Pickett, J. A., Hailu, G. W., & Khan, Z. R. (2018). A climate-adapted push-pull system effectively controls fall armyworm Spodoptera frugiperda (J. E. Smith), in maize in East Africa. *Crop Protection, 105*, 10–15.

Mojica, F. J., Díez-Villaseñor, C., García-Martínez, J., & Almendros, C. (2009). Short motif sequences determine the targets of the prokaryotic CRISPR defence system. *Microbiology, 155*, 733.

Molden, D., Oweis, T., Steduto, P., Bindraban, P., Hanjra, M. A., & Kijne, J. (2010). Improving agricultural water productivity: Between optimism and caution. *Agricultural Water Management, 97*, 528–535.

Moretti, C. L., Mattos, L. M., Calbo, A. G., & Sargent, S. A. (2010). Climate changes and potential impacts on postharvest quality of fruit and vegetable crops—A review. *Food Research International, 43*, 1824–1832.

Myers, S. S., Smith, M. R., Guth, S., Golden, C. D., Vaitla, B., Mueller, N. D., Dangour, A. D., & Huybers, P. (2017). Climate change and global food systems: Potential impacts on food security and undernutrition. *Annual Review of Public Health, 20*(38), 259–277.

Myers, S. S., Zanobetti, A., Kloog, I., Huybers, P., Leakey, A. D. B., Bloom, A. J., Carlisle, E., Dietterich, L. H., Fitzgerald, G., Hasegawa, T., Holbrook, N. M., Nelson, R. L., Ottman, M. J., Raboy, V., Sakai, H., Sartor, K. A., Schwartz, J., Seneweera, S., Tausz, M., & Usui, Y. (2014). Increasing CO_2 threatens human nutrition. *Nature, 510*, 139–142.

Nelson, G., Bogard, J., Lividini, K., Arsenault, J., Riley, M., Sulser, T. B., Mason-D'Croz, D., Power, B., Gustafson, D., Herrero, M., Wiebe, K., Cooper, K., Remans, R., & Rosegrant, M. (2018). Income growth and climate change effects on global nutrition security to mid-century. *Nature Sustainability, 1*, 773–781.

Nelson, G., Palazzo, A., Ringler, C., Sulser, T., & Batka, M. (2009). *The role of international trade in climate change adaptation* (ICTSD and Food & Agricultural Trade Issue Brief No. 4). International Centre for Trade and Sustainable Development (ICTSD) and International Food & Agricultural Trade Policy Council.

Nelson, G. C., Rosegrant, M. W., Palazzo, A., Gray, I., Ingersoll, C., Robertson, R., Tokgoz, S., Zhu, T., Sulser, T. B., Ringler, C., Msangi, S., & You, L. (2010). *Food security, farming, and climate change to 2050: Scenarios, results, policy options*. International Food Policy Research Institute.

Nicholls, R. J., & Cazenave, A. (2010). Sea-level rise and its impact on coastal zones. *Science, 328*(5985), 1517–1520.

Oliver, T., Boyd, E., Balcombe, K., Benton, T., Bullock, J., Donovan, D., Feola, G., Heard, M., Mace, G. M., Mortimer, S. R., Nunes, R. J., Pywell, R. F., & Zaum, D. (2018). Overcoming undesirable resilience in the global food system. *Global Sustainability, 1*(e9), 1–9.

Parry, M. L., Rosenzweig, C., Iglesias, A., Livermore, M., & Fischer, G. (2004). Effects of climate change on global food production under SRES emissions and socio-economic scenarios. *Global Environmental Change, 14*, 53–67.

Peterman, A., Behrman, J. A., & Quisumbing, A. R. (2014). A review of empirical evidence on gender differences in nonland agricultural inputs, technology, and services in developing countries. In A. R. Quisumbing, R. Meinzen-Dick, T. L. Raney, A. Croppenstedt, J. A. Ehrman, & A. Peteran (Eds.), *Gender in agriculture: Closing the knowledge gap* (pp. 145–186). Springer.

Phalkey, R. K., Aranda-Jan, C., Marx, S., Höfle, B., & Sauerborn, R. (2015). Systematic review of current efforts to quantify the impacts of climate change on undernutrition. *Proceedings of the National Academy of Science USA, 112*(33), 4522–4529.

Pingali, P., Alinovi, L., & Sutton, J. (2005). Food security in complex emergencies: Enhancing food system resilience. *Disasters, 29*, 5–24.

Portier, C. J., Thigpen, T. K., Carter, S. R., Dilworth, C. H., & Grambsch, A. E. (2013). *A human health perspective on climate change: A report outlining the research needs on the human health effects of climate change*. Environmental Health Perspectives/National Institute of Environmental Health Sciences, Research Triangle Park. https://digital.library.unt.edu/ark:/67531/metadc950189/

Prosperi, P., Allen, T., Cogill, B., Padilla, M., & Peri, I. (2016). Towards metrics of sustainable food systems: A review of the resilience and vulnerability literature. *Environment Systems and Decisions, 36*(1), 3–19.

Quandt, A., Neufeldt, H., & McCabe, J. T. (2017). The role of agroforestry in building livelihood resilience to floods and drought in semiarid Kenya. *Ecology and Society, 22*(3), 10.

Quandt, A., Neufeldt, H., & McCabe, J. T. (2019). Building livelihood resilience: What role does agroforestry play? *Climate and Development, 11*(6), 485–500.

Robinson, L. W., Ericksen, P. J., Chesterman, S., & Worden, J. S. (2015). Sustainable intensification in drylands: What resilience and vulnerability can tell us. *Agricultural Systems, 135*, 133–140.

Rockström, J. (2003). Resilience building and water demand management for drought mitigation. *Physics and Chemistry of the Earth, Parts A/B/C, 28*(20–27), 869–877.

Rockström, J., & Barron, J. (2007). Water productivity in rainfed systems: Overview of challenges and analysis of opportunities in water scarcity prone savannahs. *Irrigation Science, 25*, 299–311.

Rosegrant, M. W., Koo, J., Cenacchi, N., Ringler, C., Robertson, R., Fisher, M., Cox, C., Garrett, K., Perez, N. D., & Sabbagh, P. (2014). *Food security in a world of natural resource scarcity: The role of agricultural technologies*. International Food Policy Research Institute.

Rosenstock, T. S., Lamanna, C., Namoi, N., Arslan, A., & Richards, M. (2019). What is the evidence base for climate-smart agriculture in East and Southern Africa? A systematic map. In T. Rosenstock, A. Nowak, & E. Girvetz (Eds.), *The climate-smart agriculture papers* (pp. 141–151). Springer.

Rosenzweig, C., Mbow, C., Barioni, L. G., Benton, T. G., Herrero, M., Krishnapillai, M., Liwenga, E. T., Pradhan, P., Rivera-Ferre, M. G., Sapkota, T., Tubiello, F. N., Xu, Y., Mencos Contreras, E., & Portugal-Pereira, J. (2020). Climate change responses benefit from a global food system approach. *Nature Food, 1*, 94–97.

Ruel, M. T. (2001). *Can food-based strategies help reduce vitamin A and iron deficiencies? A review of recent evidence*. International Food Policy Research Institute.

Ruel, M. T., Garrett, J. L., & Yosef, S. (2017). Food security and nutrition: Growing cities, new challenges. *Global food policy report* (pp. 24–32). International Food Policy Research Institute.

Saito, N. (2013). Mainstreaming climate change adaptation in least developed countries in South and Southeast Asia. *Mitigation and Adaptation Strategies for Global Change, 18*, 825–849.

Schimmelpfennig, D. (2016). *Precision agriculture technologies and factors affecting their adoption*. United States Department of Agriculture. https://www.ers.usda.gov/amber-waves/2016/december/precision-agriculture-technologies-and-factors-affecting-their-adoption/

Schwan, S., & Yu, X. (2018). Social protection as a strategy to address climate-induced migration. *International Journal of Climate Change Strategies and Management, 10*, 43–64.

Serfilippi, E., & Ramnath, G. (2018). Resilience measurement and conceptual frameworks: A review of the literature. *Annals of Public and Cooperative Economics, 89*(4), 645–664.

Shi, L., Chu, E., & Debats, J. (2015). Explaining progress in climate adaptation planning across 156 U.S. municipalities. *Journal of the American Planning Association, 81*(3), 191–202.

Signorelli, S., Azzarri, C., & Roberts, C. (2016). *Malnutrition and climate patterns in the ASALs of Kenya: A resilience analysis based on a pseudopanel dataset*. Report prepared by the Technical Consortium, a project of the CGIAR (Technical Report Series No. 2: Strengthening the evidence base for resilience in the Horn of Africa). International Livestock Research Institute, Nairobi.

Silici, L., Ndabe, P., Friedrich, T., & Kassam, A. (2011). Harnessing sustainability, resilience and productivity through conservation agriculture: The case of Likoti in Lesotho. *International Journal of Agricultural Sustainability, 9*(1), 137–144.

Springmann, M., Mason-D'Croz, D., Robinson, S., Garnett, T., Charles, H., Godfray, J., Gollin, D., Rayner, M., Ballon, P., & Scarborough, P. (2016). Global and regional health effects of future food production under climate change: A modelling study. *The Lancet, 387*(10031), 1937–1946.

Stevanovic, M., Popp, A., Lotze-Campen, H., Dietrich, J. P., Müller, C., Bonsch, M., Schmitz, C., Bodirsky, B., Humpenöder, F., & Weindl, I. (2016). The impact of high-end climate change on agricultural welfare. *Science Advances, 2*(8), e1501452.

Stone, J., & Rahimifard, S. (2018). Resilience in agri-food supply chains: A critical analysis of the literature and synthesis of a novel framework. *Supply Chain Management, 23*(3), 207–238.

Thacker, S., Adshead, D., Fay, M., Hallegatte, S., Harvey, M., Meller, H., O'Regan, N., Rozenberg, J., Watkins, G., & Hall, J. W. (2019). Infrastructure for sustainable development. *Nature Sustainability, 2*, 324–331.

Tirado, M. C., Clarke, R., Jaykus, L. A., McQuatters-Gollop, A., & Frank, J. M. (2010). Climate change and food safety: A review. *Food Research International, 43*, 1745–1765.

Tirado, M. C., Hunnes, D., Cohen, M. J., & Lartey, A. (2015). Climate change and nutrition in Africa. *Journal of Hunger & Environmental Nutrition, 10*(1), 22–46.

Verchot, L., van Noordwijk, M., Kandji, S., Tomich, T., Ong, C., Albrecht, A., Mackensen, J., Bantilan, C., Anupama, K., & Palm, C. (2007). Climate change: Linking adaptation and mitigation through agroforestry. *Mitigation and Adaptation Strategies for Global Change, 12*, 901–918.

Vonthron, S., Dury, S., Fallot, A., & Bousquet, F. (2016). L'intégration des concepts de résilience dans le domaine de la sécurité alimentaire: Regards croisés. *Cahiers Agriculture, 25*, 64001.

Weindl, I., Lotze-Campen, H., Popp, A., Müller, C., Havlik, P., Herrero, M., Schmitz, C., & Rolinski, S. (2015). Livestock in a changing climate: Production system transitions as an adaptation strategy for agriculture. *Environmental Research Letters, 10*, 094021.

Wheeler, T., & von Braun, J. (2013). Climate change impacts on global food security. *Science, 341*, 508–513.

Wiebe, K. D., Lotze-Campen, H., Sands, R. D., Tabeau, A., van der Mensbrugghe, D., Biewald, A., Bodirsky, B., Islam, S., Kavallari, A., Mason-D'Croz, D., Müller, C., Popp, A., Robertson, R., Robinson, S., van Meijl, H., & Willenbocke, D. (2015). Climate change impacts on agriculture in 2050 under a range of plausible socioeconomic and emissions scenarios. *Environmental Research Letters, 10*, 85010.

Wilson, G. (2010). Multifunctional 'quality' and rural community resilience. *Transactions of the Institute of British Geographers, 35*(3), 364–381. http://www.jstor.org/stable/40890993

Woodfine, A. (2009). *The potential of sustainable land management practices for climate change mitigation and adaptation in Sub-saharan Africa*. Food and Agriculture Organization of the United Nations.

Xu, L., Marinova, D., & Guo, X. (2015). Resilience thinking: A renewed system approach for sustainability science. *Sustainability Science, 10*, 123–138.

Yin, R. K. (2009). *Case study research: Design and methods* (4th ed.). Sage.

Zilberman, D., Zhao, J., & Heiman, A. (2012). Adoption versus adaptation, with emphasis on climate change. *Annual Review of Resource Economics, 4*, 27–53.