BACKGROUND PAPER

RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security

RURAL LIVELIHOODS, FOOD SECURITY AND RURAL TRANSFORMATION UNDER CLIMATE CHANGE

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Executive summary

Despite decades of attention to agricultural development, food security and rural poverty, poverty and food insecurity remain, especially amongst rural dwellers in Asia, Africa and Central America. With climate change the challenges only increase and will further intensify as extreme events and variable weather patterns make small-scale production even more difficult.

For any list of recommendations, leverage points or action points, the criticism can easily be that we have heard it all before. There are no silver bullets and some actions and strategies can have mixed outcomes, though nascent and yet-to-be-developed technologies could shift rural livelihoods, agriculture and the broader food systems in unexpected ways in the coming decade, both positively and negatively.

Our thesis is that transformational change in rural livelihoods is needed for climate change adaptation, that this change needs to embrace the broader food system, and that these actions can have benefits in multiple dimensions beyond climate change adaptation: poverty, nutrition, employment and the environment. If transformational change is to be achieved, several elements will be needed in synergy, with less or more emphasis on particular elements, depending on context and considering household heterogeneity. Given that in many places there are at most 12 harvests left to achieve the Sustainable Development Goals (SDGs), urgency in the implementation of the actions under the following elements is imperative:

About this paper

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- Firstly, and fundamentally, the policy and institutional environment needs to change, to provide appropriate incentives for transformational change. Policies that can generate or enhance risks should be avoided. Key objectives in the policy domain include promoting landscape planning and management, rethinking subsidies, making markets work, reducing risks in agriculture, improved water supply in the less humid zones, improved soil and water conservation, enhanced good governance in all sectors, tenure reform, and targeting the poorest of the poor with productive social safety nets and alternative options. In many cases policy action is required outside the agricultural sector and a much stronger focus on more localized enabling environments will be needed, such as rethinking of current financial incentive mechanisms for state budget allocation that discourage local authorities from implementing sustainable policies, policies on migration, policies that enhance environmental standards and law enforcement and promotion of participatory and gender-sensitive decision-making and free trade policies.

- Secondly, appropriate climate-resilient practices and technologies need to be identified and further developed, and perhaps more importantly, scaled up. Technologies are highly context specific, but considering small-scale producers, some key areas for action are around solar micro-irrigation, technologies for high value commodities that link to changing urban markets (e.g., climate-smart dairy production, small-scale aquaculture, horticulture), nature-based solutions such as ecosystem-based adaptation, diversified systems that help manage climate risk, likely early winners in new technology such as alternative protein sources for humans and livestock, and food storage innovations. Stress tolerance in crops and livestock will be important, in particular for closing yield gaps in some of the world's poorest and most climate-vulnerable regions, with more attention required for some of the lesser researched and lesser incentivized crops (e.g., in the African context: beans, cassava, millet, plantain/banana, potato and sorghum) and to pests and diseases. Greater focus on rural mechanization and post-harvest storage and processing relevant to small-scale producers can also be a boost to rural entrepreneurship. These technologies need to be identified based on local needs and need to be transferred to local people.

- Thirdly, orders of magnitude more investments are required, however, these are largely expected to be from the private sector (e.g., role of large national and multinational corporations in adaptation not only through their potential to finance projects but also to develop technologies and innovative solutions) and driven by appropriate government policies, with investments coming from multiple sources used to leverage private investments, e.g., through de-risking agriculture. Innovation in financial models and in the use of climate finance is sorely needed. Index-based insurance is advancing rapidly and is likely to be an important risk mitigation option.

- Fourthly, given that different agricultural value-chains and market configurations can provide big opportunities for rural producers, considerable attention needs to be focused on reshaping supply chains, food retail, marketing and procurement. This must address food loss and waste issues, shifts in consumption towards healthier diets, building the resilience of supply chains, and, most importantly, ensuring that supply chains link to small-scale producers and enhance rural employment opportunities.

- Fifthly, we must realize the digital era for rural livelihoods, agriculture and food systems. Agriculture is behind other sectors in digitalization, and digital agriculture has the potential to revolutionize agriculture and supply chains. For example, two-way digital extension services integrated with weather advisories can change information flows to and from small-scale producers, and change how farmers respond to climate risk. Digitalization can also enhance local networking and increase rural employment opportunities.

- Sixthly, and to address the issue that a strong private sector approach is being advocated, considerable attention needs to be given to empowering producer and consumer organizations, women, youth and marginalized groups such as indigenous communities to promote local action, strengthen negotiating power and increase access to resources. Local networking has been shown to have important positive consequences for climate adaptation. Capacity development must run through all the elements.

Taken together, implementing these elements for action simultaneously would constitute a new approach to innovation and enabling it: co-creating new knowledge, "renovating" existing but as-yet under-utilized scientific and indigenous knowledge, and sharing knowledge between all stakeholders and levels in the food system, producers and consumers alike.

Fostering transformation in rural livelihoods, agriculture and food systems will mean very different things for different sub-sectors of the rural population, where we recognize at least four livelihood types: "stepping up" (investing in agricultural assets, and purchasing at least some inputs or services); "stepping out" (accumulating assets that allow investments in or switches to new activities outside agriculture); "hanging in" (maintaining and protecting current levels of wealth and welfare in the face of threats of stresses and shocks; focused on subsistence or low-input agriculture), and "food insecure" (chronically food-insecure, some landless or reliant on casual agricultural or non-agricultural labour). Market approaches are likely to benefit those stepping up or stepping out, while for others—often the majority in many communities—food insecurity can increase, and the population of those hanging in could increase.

Thus, we have to recognize differentiated pathways to adaptation—tailored to different sectors of the population often with multiple pathways in the same geography. We discuss five main pathways:

1. Increasing market integration and/or consolidating land so as to step up
2. Climate-informed shifts in the farming system so as to step up
3. From landless to small-scale entrepreneurship (including highly intensive production on micro landholdings)
4. Climate-informed productive social safety nets and nature-based solutions for those least integrated into markets
5. Exiting/reducing agriculture in the livelihood portfolio

Some key interventions are shown in Table 1.

TABLE 1 Pathways and interventions needed

Pathway	Interventions for each pathway and the elements addressed
#1. Increasing market integration and/or consolidating land so as to step up	• Increase access to credit, technology, and infrastructure • Promote risk reducing options • Implement tenure reforms, enhance land rental markets • Strengthen farming organizations, cooperatives and similar forms of collective action • Farmers to organize, network and improve access to information to negotiate with industry and have their voices heard in decision-making processes
#2. Climate-informed shifts in the farming system so as to step up	• Develop new technologies that deal with multiple and interacting stresses • Provide training and information about new options • Strong policy support and investments to shift farming systems • Access to credit, technology, and infrastructure • Promote risk reducing options
#3. From landless to small-scale entrepreneurship	• Strong policy support and investments to incentivize new farming systems and innovative methods of production, such as urban farming and floating agriculture • Provide training, microcredit, and appropriate bundles of choices of technologies
#4. Climate-informed productive social safety nets and nature-based solutions for those least integrated into markets	• Strong policy support for social safety nets, for schemes for payments for environmental services and for ecosystems conservation • Implement cash transfer income tools • Capacity building for implementing ecosystem and community-based adaptation approaches • Development of business cases for conservation • Strengthen farming organizations, cooperatives and similar forms of collective action • Farmers' to organize, network and improve access to information to negotiate with industry and have their voices heard in decision-making processes
#5. Exiting/reducing agriculture in the livelihood portfolio	• Develop policy measures to support future livelihoods of migrants • Implement policies to develop secondary and tertiary industries in rural areas • Develop policies and investments in education and specific skills for non-farm activities • Use of media for education and establishment of technology information centres to identify promising off-farm opportunities • Enhance opportunities around digital agriculture

1. Introduction: rural livelihoods in transition?

In 2017, 3.4 billion people lived in rural areas, most in low (15%) and middle income (79%) countries[i], many deriving their income from small-scale agriculture, including fishing and livestock raising. Globally, there are about 570 million farms, most of which (circa 500 million) are less than 2 ha, accounting for about 12% of the world's agricultural land.[1] Small and medium farms (≤50 ha) produce 51–77% of nearly all nutrients.[2] Poverty rates are higher in rural than urban areas (e.g., in 2013, 18.2% of rural residents and only 5.5% for urban residents were in extreme poverty, and food insecurity is also slightly higher for rural than urban residents.[3,4]

This paper is focused on the rural poor with an emphasis on the developing world, many connected to the land, agriculture and ecosystem services; and vulnerable to a range of risks including climate change. The main objective of the paper is to advocate for actions and research-for-development that builds resilient and food- and nutritionally-secure rural livelihoods; and fosters differentiated and context-appropriate rural adaptation pathways.

Rural conditions vary markedly across continents (Figure 1), and even within countries and districts. Most small and very small farms are in Asia, with sub-Saharan Africa (SSA) having a mix of small to large farms, and Latin America dominated by large and very large farms, but with smaller farms in Central America and the Andes.[5] Poverty is concentrated in SSA and South Asia, but high levels also found in Latin America and the Caribbean (LAC) regions with smaller farms.[6] Africa has the highest prevalence of undernutrition – 21% of the population (256 million people), with Asia at 11% (515 million) and LAC at 5%.[7] Even though South America has lower numbers of undernourished the number did increase from 20.7 to 21.4 million between 2016 and 2017.[8]

In Asia, rural areas were transformed through the Green Revolution through a process driven by state policies and R&D investments, mediated by markets and embracing small-scale producers.[9] This was matched by urbanization and emerging industries that allowed farmers to enter non-farm employment.[10] Initially most rural households were subsistence producers, but with better functioning markets and improved transport and communications in rural areas, households produced for the market as well as diversifying into non-farm activities to increase incomes. The Green Revolution contributed to widespread poverty reduction and averted hunger for millions of people but left some people behind, particularly those in marginal rainfed areas, and had several negative, unanticipated gender-related and environmental outcomes.[11] Other changes occurred and are continuing, such as the major increase in aquaculture.

By contrast, rural transformation in LAC – where land distribution is bimodal (heavy concentrations of both small and large landholdings) – has been driven by investments in new technology and commercial opportunities that have benefitted large farms, rather than small-scale producers, resulting in persistent poverty of small-scale producers. In a study of 10,000 territories in 11 countries, only 12% of them experienced decade-long development dynamics that simultaneously resulted in economic growth, poverty reduction, and improved income distribution.[12] Some 29% had failed in all three dimensions. The authors identified five factors that facilitated development, factors demonstrating the important institutional dimensions of poverty alleviation: (i) level of equity in agrarian structures and natural resource governance structures; (ii) sectoral and organizational diversity of territorial economic structures and intensity of interactions among them; (iii) strength of linkages with dynamic markets external to the territory; (iv) presence of small/medium cities within or close to the otherwise rural territory; and (v) ways in which territories deal with large public investments. Positive developments depended on "transformative social coalitions" characterized by a convergence in vision by, and actions of, diverse social actors that are committed to sustained action over a long period of time.

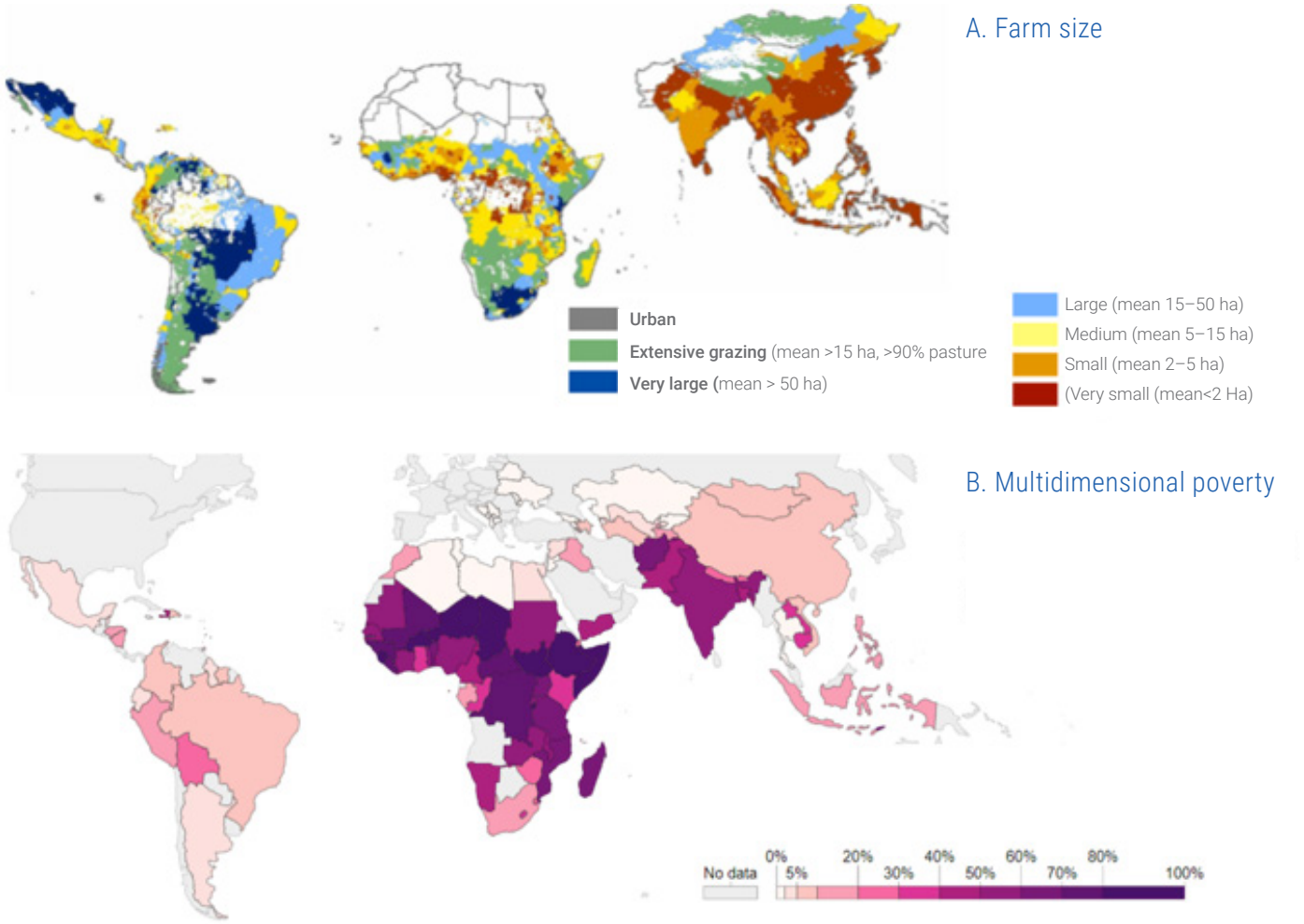
SSA deviates considerably from the Asian path of structural transformation.[13] Urbanization is proceeding slower than in Asia, because of the slow pace of industrialization, thus providing limited opportunities for leaving agriculture and entering non-farm employment.[14] However, the urbanization trend is still significant. Globally rural populations are expected to decline by 2050, while in SSA they are expected to increase, with further decreases

[i]Retrieved from https://data.worldbank.org/indicator/SP.RUR.TOTL

in farm size (Figure 2). Agricultural productivity in SSA remains low because of limited irrigation, variable rainfall, and impoverished and degraded soils, with producers unwilling to invest in new technologies due to high risks, poorly developed markets and insecure land tenure. Poor governance and pervasive inequality in the provision of services and incentives to women and certain marginalized groups also characterize SSA situation. National food demand is increasingly met by food imports. While farming (including pastoralism) provides a primary option for gainful employment, it may increasingly be unable to meet livelihood needs in the future, pushing many into low-return non-farm sectors.[15]

Despite the differences amongst continents, there are also many similarities in the transformation processes underway. A common trend involves what has been termed deagrarianization (or deactivation when the process is not permanent but only temporary – see Shackleton and Hebinck 2018, for example).[16] Deagrarianization is characterized by diversification of rural livelihoods, increased agricultural and non-

FIGURE 1 A. Mean farm size and B. percentage of population in multi-dimensional poverty in three global regions.[17,18]



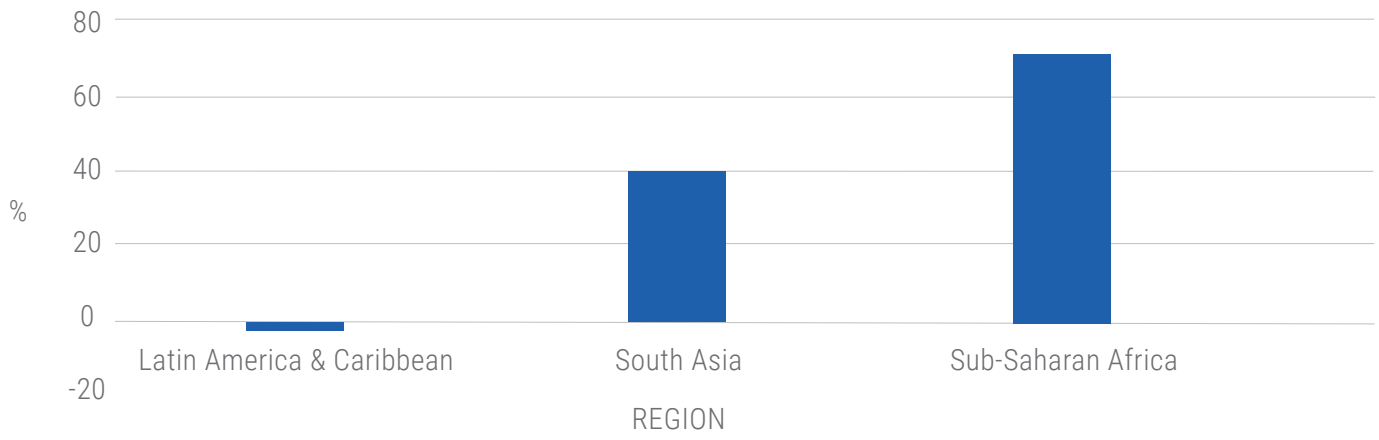
Note: The multi-dimensional poverty index is constructed from ten indicators across three core dimensions: health, education and living standards.

agricultural wage labour, more commercialization of forest products, and temporary and permanent migration to new livelihood options in urban centres.[19] Historically, much migration, particularly for poorer migrants, has been seasonal, temporary, and remaining within rural areas.[20] These patterns are already changing, however, especially in SSA, with increasing migration from rural to urban centres, driven by various factors including climate change[ii].[21] Employment in the areas from which migrants originate may be scarce, but the wage levels for poor migrants at their destination may be only marginally higher, and in addition may come with new risks. Deagrarianization is most advanced in LAC and much has been written about these trends in SSA, even though deagrarianization is least advanced in SSA (Figure 3). Specialization in on-farm activities continues to be common in SSA (on average practiced by 52% of households in the sample of Davis et al. (2017), compared with 21% in other regions).[22] However, cases of extreme deagrarianization, even in the absence of good alternatives, have taken place in some SSA regions, highlighting the need for livelihood options outside agriculture (Box 1).

Despite the trend of deagrariainization, all three regions are still characterized by the persistence of small-scale producers.[23] Reasons are many and include (not all occur in the same place): (i) lack of alternative options; (ii) strong cultural ties to land; (iii) policies limiting land sales and land rental markets; (iv) subsidies to small-scale farming; (v) farmers holding onto small pieces of land that would by themselves be sub-livelihood in size, given households have other sources of income; (vi) smallholdings being productive relative to large units, e.g., for wet rice-based smallholdings in East Asia; (vii) emergence of small-scale or micro-mechanization and machine rental markets, and (viii) incorporation of local natural resource-based activities such as charcoal production into livelihood portfolios.

[ii] By 'climate change' we include climate variability, given the recognition that adapting small-scale producers to climate change requires developing resilience to the risks associated with natural climate variability. Given that anthropogenic forcing interacts with natural climate variability, producers experience climate change largely as shifts in the frequency and severity of extreme events, and in new weather patterns.

FIGURE 2 Growth in rural populations (1990 – 2017) in sub-Saharan Africa, South Asia and Latin America and the Caribbean.



Source: World Bank staff estimates based on the United Nations Population Division's World Urbanization Prospects: 2018 Revision.

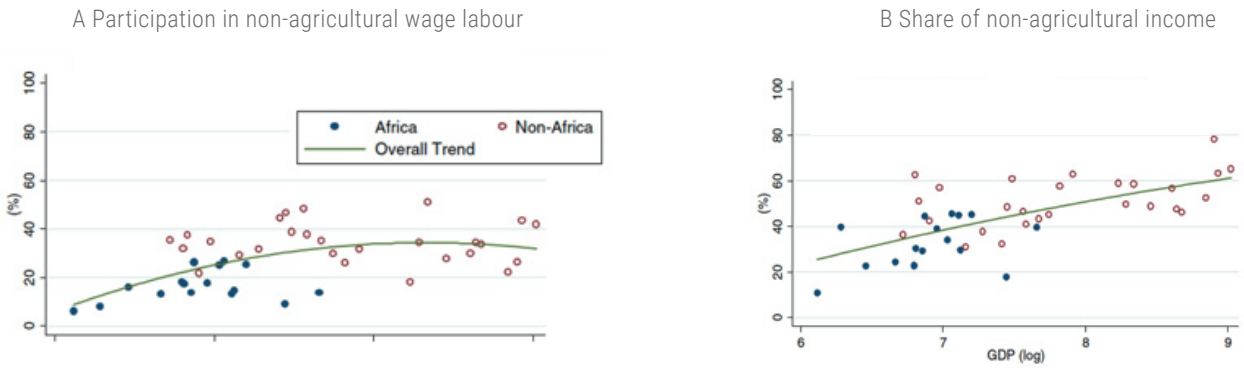
Another commonality amongst regions, though predominantly an urban phenomenon, is rising obesity and diabetes, giving rise to the need to consider the whole food system and to promote diversified production systems that enhance nutrition. Although green revolution approaches have increased calorie consumption, dietary diversity decreased for many poor people, and micronutrient malnutrition persisted.[24] Policies tend to focus on staple crops, thus limiting growth in more nutrient-rich vegetables, pulses, legumes, and animal-source foods.

The empirical relationships between income-generating strategies, diversification and welfare are not straightforward, and the speed and extent of deagrarianization globally depends on many factors, including agricultural potential, development in non-agricultural sectors, location in relation to infrastructure, markets and cities, changing values and ambitions amongst the younger generation, and household characteristics (especially those that help in overcoming barriers to entry into non-agricultural livelihoods).[25,26,27] As an example, with respect to location, Fafchamps and Shilpi (2002) find that in Nepal, agricultural wage employment is concentrated in rural areas close enough to cities to specialize in high-value horticulture, but not so close as to be taken over by unskilled 'urban' wage labour opportunities.[28] Davis et al. (2017) find that better-off households have a higher participation in (and greater share of income from) non-farm activities.[29]

BOX 1 Abandoning farming in South Africa[30,31]

Livelihoods in rural Eastern Cape are on new trajectories, with agricultural production declining markedly, though with some households specializing in more intensive home gardens. Many factors are influencing the shift, including reduced labour availability due to HIV/AIDS, increased risk associated with dryland cropping due to frequent poor seasons, and the availability of social security cash transfers. Higher level factors include lack of investment in communal lands and insecure land tenure. This is deagrarianization but without options to escape poverty, leading to entrenched rural poverty and loss of social capital including a rise in rural crime and drug use. This case may represent an extreme situation given South Africa's violent political history and marked inequality, although similar (but not as extreme) trends are also see in other parts of southern Africa.

FIGURE 3 Share of rural households' participation in non-agricultural wage labour and share of non-agricultural income, by per capita gross domestic product (GDP) in 2005 Purchasing Power Parity (PPP) dollars.



Source: Davis et al. 2017.[32]

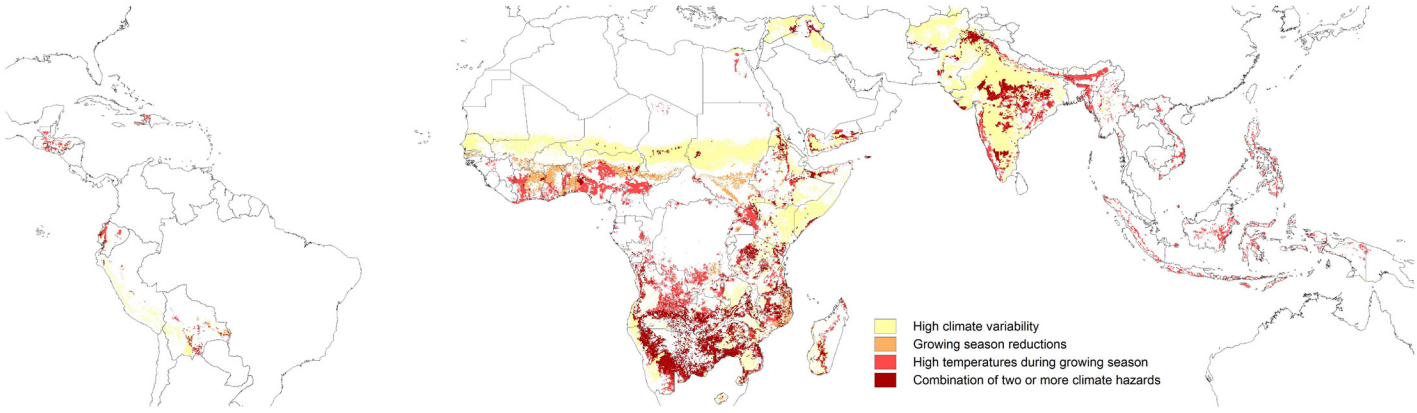
2. Risks to rural livelihoods and rural transformation

Multiple and inter-related risks impact rural dwellers' choices and livelihoods, and influence the potential of small-scale farmers and pastoralists to enhance wellbeing and food security.[33] Climate-related disasters impact poor countries, and poorer sectors of the population disproportionately. Climate shocks come in many forms: changes in seasonality, heavy storms and excessive rainfall, storm surges and salinization, flooding, droughts and extreme heat events. Other risks, some made worse by climate variability, include plant and animal pests and diseases, and price fluctuations of agricultural inputs and products. Small-scale producers also often face uncertain markets: unreliable input markets, transport bottlenecks, and gluts in production that drive prices down. Gains in ending hunger and malnutrition are being eroded by more frequent and intense climate extremes.[34] High vulnerability extends over 10.84 million km^2, with some 1.11 billion inhabitants, covering large areas of SSA, South Asia and some pockets of LAC (Figure 4). Small-scale producers often face other types of risk too, such as those associated with poor health and nutrition, conflict and economic shocks, for example.

Households deal with climate shocks through risk aversion behaviour prior to the shock and through responding to the shock. Risk aversion reduces the chances of breaking out of poverty, as households in risky environments are unwilling to invest in improved production practices and technologies.[35] Households tend to use practices tailored to more adverse conditions and are therefore unable to make the most of average growing seasons, let alone good seasons. Risk aversion extends beyond producers to institutions and market players, limiting investments in the development of agricultural value chains. With severe climate shocks, vulnerable households employ a range of strategies to cope, further increasing vulnerability, e.g., defaulting on loans, selling productive assets (e.g., livestock), removing children from school, reducing food intake, and exploiting natural resources.

The above discussion focusses on households, but there are also a host of risks to the entire small-scale sector, such as urban bias in policy making, lack of policy support to small-scale producers, and shortfalls in institutional capacities and insecure tenure.[36] Small-scale producers are often at a disadvantage relative to large landholders, through policies affecting land, investment and agriculture.[37] In LAC small-scale producers need to be extremely organized in order to secure policy and

FIGURE 4 Areas of High Agricultural Risk for Different Climate Hazards in Vulnerable Areas.



Notes: Areas of vulnerability projected for the 2050s based on RCP 8.5 overlaid on cropland and pastureland (Ramankutty et al. 2008, https://doi.org/10.1029/2007GB002952) with respect to: (1) areas where the coefficient of variation of annual rainfall is currently greater than the median value for the global tropics; (2) reduction in the number of reliable crop growing days per year below 90 mostly due to changes in rainfall distributions and amounts; (3) increases in average maximum temperature during the primary growing season above 30°C.

Methods as in Jones and Thornton, 2013 (https://doi.org/10.1016/j.agsy.2012.08.002) and 2015 (https://doi.org/10.1016/j.agsy.2015.07.003), ensemble mean of 17 climate models from the Coupled-Model Inter-comparison Project 5 (CMIP5) of the IPCC.

investment support.[38] In parts of SSA there has been rising land consolidation, to the benefit of traditional authorities, decision makers and non-rural actors and to the detriment of small-scale producers.[39] Similarly, pastoralism has been put under increasing pressure as a result of sedentarization policies, usually to the detriment of pastoral livelihoods.[40]

Policies promoting specific practices can increase risks. For example, interventions promoting intensification can be inappropriate, as intensification practices may be more impacted by climate than traditional practices. Intensification has resulted in some extremely negative social outcomes. It is argued that farmer suicides in India are largely a consequence of the push to intensified, commercialized agriculture.[41] Carleton (2017) identified increasing temperatures as a significant contributing factor.[42] While the reasons for farmer suicides are likely to be complex, it does appear that indebtedness due to efforts for intensification and commercialization of agriculture and the factors associated with it are important drivers of farmer suicides in India.[43,44] Dawson et al. (2016) demonstrate for Rwanda – generally seen as a positive example of agricultural development – that only a relatively wealthy minority were able to adhere to the modernization drive, and policies appear to be exacerbating landlessness and inequality (e.g., subsistence practices disrupted, local systems of knowledge, trade, and labour impaired, and land tenure security reduced).[45] Intensification technologies – such as stress-tolerant varieties should reduce vulnerability, but if the new variety comes with greater costs or more labour, the reduced bio-physical vulnerability can be offset by increased socio-economic vulnerability.[46]

Other potential challenges to rural livelihoods include the rising feminization of agriculture (Box 2), increased youth unemployment and poor health. Feminization, often the result of male out-migration, can leave the household with labour constraints (Box 3), but in some situations may help to decrease livelihood vulnerability.[47] Other places are seeing female out-migration, leaving the very young in the care of the elderly.[48] Feminization may result in a shift to other farming practices (for example, in many parts of rural Kenya, livestock are managed by men and crops by women), with possible negative or positive outcomes. Differential vulnerability, power imbalance and gender and class inequalities can be further entrenched in development and market initiatives.[49] Youth unemployment is recognized as a key problem, and in extreme conditions can lead to social unrest, rural crime and drug abuse (Box 1). Poor health, or at least reduced labour productivity, can be climate-induced because of extreme heat events. Climate, through flood events, is also influencing disease outbreaks such as cholera. But diseases unlinked to climate also wreak havoc on rural communities; an example is HIV/AIDS and its implications for available labour (Box 1). Another potential risk relates to the commercial production of non-food crops, as is the case of sugarcane cultivation among small-scale farmers in Uganda. According to Mwavu et al. (2018), as a result of the expansion of this crop, the majority of households growing sugarcane in Uganda are cultivating fewer crop varieties, lack adequate and nutritious foods, and do not have enough income to purchase food.[50] The latter responds to changes in food systems, e.g. the demand of new types of foods with a smaller environmental footprint and better quality that has caused an excess of sugarcane production associated with lower incomes for farmers to purchase food.

Changes in the food system, such as growing demand for new kinds of food and of better quality by an urbanizing population, the growing power of supermarkets, and consumer and advocacy demands for foods with lower environmental footprints, are both a risk to and an opportunity for small-scale producers. If unable to meet food system demands, small-scale producers will be side-lined by larger-scale producers and imports from other countries.

There are many risks facing specific individuals, households and regions, such as political economy risks that might have negative impacts on local people, political instability, social conflicts (civil war), elite capture, corruption, poorly designed and poorly enforced laws. Much better understanding of how they may affect the transformation processes underway and the factors influencing those pathways, and the relationships between agricultural development initiatives, vulnerability and poverty, are essential if appropriate interventions are to be identified and taken to scale.

BOX 2 Gender differentiation in African small-scale systems

Bryceson (2019) summarizes trends in gender and generational labour allocation using data from several countries.[51] Agricultural labour participation in the rural areas by age is shown below (panel A). Apart from in Ghana and Mali[iii], women dominate agriculture throughout their life cycle. These patterns are broadly similar for urban agriculture. African women's agricultural effort continues to be primarily focussed on subsistence food production, achieving 20-30% lower agricultural productivity than men. This "productivity gap" may arise because women farm smaller plots than men and have lower resource endowments with respect to fertilizer, seeds and extension inputs. Social barriers and norms that act against the full and rightful engagement of women in productive work that is remunerated, rewarded, and incentivized adequately also explain this productivity gap.

Male-female sex ratios of participation by age group, 2010s. Dark blue, overwhelmingly male; yellow, roughly gender balanced; dark red, overwhelmingly female.

A: Rural agricultural sector							B: Rural non-agricultural sector						
Country	Age groups					% total work population	Country	Age groups					% total work population
	15-24	25-34	35-44	45-54	55-64			15-24	25-34	35-44	45-54	55-64	
Ghana	1.26	0.92	0.93	1.01	1.08	29.0	Ghana	0.97	1.51	1.74	1.67	1.44	8.9
Zambia	0.75	0.84	0.98	0.93	0.93	34.6	Zambia	0.81	1.29	1.77	1.73	1.80	6.3
Mali	1.51	1.52	1.84	1.92	2.69	36.5	Mali	1.75	2.66	3.08	2.50	1.87	8.2
Tanzania	1.06	0.74	0.60	0.78	0.94	46.2	Tanzania	1.41	2.02	1.60	1.89	2.25	11.1
Rwanda	0.82	0.77	0.71	0.70	0.72	55.7	Rwanda	1.61	2.10	1.87	1.83	2.07	17.6
Kenya	0.84	0.68	0.70	0.71	0.86	27.5	Kenya	1.40	1.57	1.64	1.75	1.79	17.7
Uganda	0.95	0.66	0.65	0.77	0.54	48.7	Uganda	1.51	2.19	2.35	2.18	2.32	14.0
Malawi	0.70	0.93	1.02	0.94	0.93	33.6	Malawi	1.77	2.24	3.42	1.93	4.41	10.5

Contrast this with the rural non-agricultural sector (panel B), which is male-dominated in all countries other than the two most urbanized, Ghana and Zambia, where the youngest age group (15–24 years) were gender balanced or slightly female-biased. Along with labour and land contraction in many small-scale systems, female resource control and labour autonomy continue to be affected by male patriarchal attitudes. Older women tend to be left behind in the countryside, though they nevertheless provide an agrarian fallback for returned migrant family members and other members engaged in local non-agricultural occupations needing subsistence food support.

Deagrarianization is a huge challenge for African governments seeking to create an enabling environment for their populations to achieve higher standards of living, reduced inequalities, and more resilient agriculture. With industry globally undergoing massive technological transformation, Africa will need to develop its own resolution to the dilemmas of adaptation, resilience building and rural livelihood opportunities in an era of both great uncertainty and potential.

[iii] Mali presents significant differences with respect to other countries. The reason for the latter is that men's work has been always dominant in the rural sector of this country, both in agriculture and non-agriculture activities.

BOX 3 Climate- and weather-induced agricultural distress, out-migration and feminization of agriculture: evidence from India

The strength of the three-way relationship between weather and climate variability, agriculture and migration appears to depend on the country, the local context in which the analysis is carried out, and the methodology used.[52,53] The prevailing rate of internal migration in India is low, compared to other countries at similar stages of development.[54] Munshi and Rosenzweig (2016) argue that in the absence of well-functioning formal insurance and credit markets, smoothing of consumption (during shocks) happens through transfer from social networks.[55] Such social insurance could serve as a barrier against migration. The non-transferability of welfare benefits between states, and the existence of home state quotas in jobs and educational institutions, also act as constraints against inter-state migration in India.

Weather and climate variability-induced agricultural distress can lead to rural-rural migration as well as short-term migration. The temporary migration of men in search of livelihood options has increased the role of women as cultivators and agricultural labourers. For example, Bhandari and Chinnappa Reddy (2015) showed for the hill state of Uttarakhand that little or no capital formation on farms managed by women of the migrant household, resulted in a significantly higher burden on women, by comparison to women of non-migrant households.[56] Pattnaik et al. (2017), through an analysis of 1981-2011 census data, reports an increasing trend of women working as agricultural labourers in most states.[57] They note that this adds to the existing heavy work load of most rural women and thus can be better described as "feminization of agrarian distress".

3. Rural livelihood adaptation and transformation

There has been undeniable progress in reducing rates of undernourishment and improving levels of nutrition and health over the last 40 years or so, although substantial regional and in-country differences remain. Nevertheless, the number of undernourished people is estimated to have increased to 821 million between 2015 and 2017.[58] At the same time there has been a rapid increase in the number of adaptation initiatives, particularly in African and lower-income countries.[59]

The overall progress of rural households in adapting to climate change is not easy to assess. One household data set that gives some insights are the baseline surveys carried out for the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) in its first two years, covering over 6000 households in target research sites in 21 lower- and middle-income countries. This dataset, while not strictly representative, constitutes a powerful set of case studies using identical data collection instruments across a wide range of situations. Thornton et al. (2018a) analysed these data using an extension of the livelihood aspirations framework of Dorward et al. (2009) to identify four household types:[60,61]

- "Stepping up". Investing in agricultural assets over the last 10 years to expand the scale or intensity of existing activities, along with purchases of at least some inputs or services;
- "Stepping out". Accumulating assets that allow investments or switches into new activities and assets; although they reported no productivity increase and no intensification investment over the last 10 years; earned income from non-agricultural activities had increased, not necessarily indicative of leaving agriculture altogether;
- "Hanging in". Maintaining and protecting current levels of wealth and welfare in the face of threats of stresses and shocks; focused on subsistence or low-input agriculture, with a primary aim of lowering risks; not well linked to markets; not actively seeking to increase production;
- "Food insecure". Agriculture-based but chronically food-insecure, with food deficits for more than five months annually; in a relatively precarious food security situation; some may be landless or reliant on casual agricultural or non-agricultural labour.

The percentage of surveyed households of each type are shown in Table 2.[62] These aggregate data hide considerable variation: most communities contain mixtures of different household types, and some communities may be in rapid transition (for example, towards more market orientation).

The proportion of households characterized as "hanging in" is high across all regions (57%), and the other households are on average equally split between the other three types. There are some large regional differences, however: East Africa has a high proportion of households that are "food insecure", while the sites in West Africa show the lowest rate of households that are "stepping out" and high rates of "hanging in". The rate of "stepping up" in South Asia is lower than might be expected, given the relatively higher rates of agricultural input use compared with East and West Africa. The sites in Latin America have the largest percentage of households characterized as "stepping up" and "stepping out." The baseline data also show that many farmers in all regions have made changes in their farming practices in the last decade. These farming changes have been made for several reasons, but markets are one key driver of changes being made in cropping practices in all sites in East Africa, West Africa and South Asia, with factors related to climate also highly influential, along with land, labour and pest issues. In the great majority of cases, the changes that have been made to date are minor, such as changing planting dates and varieties.

For one of the East African sites in Table 2 (northern Tanzania), however, a resurvey by Fraval et al. (2018) found that despite relatively high levels of poverty, 77% of households had made changes in farm practices in the three years since the CCAFS baseline survey.[63] There was little change in household incomes for the 60% of subsistence households in the sample, but some of the other households had managed to expand their cropping areas and increase crop and off-farm income (although the longer-term risks and costs that may be associated with such expansion are not yet known). The most substantial changes observed were related not to any specific agricultural intervention but more to changing personal circumstances and expanded rural-urban market linkages. This suggests that households in rural sites with good urban connections can be both agile and diverse. Similar changes were observed in central Tanzania, with rising incomes in this case being due in part to cultivation of sunflower as a cash crop.[64] Such dynamism makes it challenging to target appropriate agricultural interventions to build resilience, both because of the pace of change and because in many situations off-farm opportunities may be as or more attractive than agriculture. A further challenge lies in separating out the additional future challenges that may be posed by climate change on desired development outcomes.

Just about all studies of rural adaptation and resilience building at local level highlight the importance of local context specificity in determining the appropriateness and performance of different agricultural interventions. The messages coming from assessments of the progress of rural small-scale producers in adapting to climate change and building their resilience are mixed: there some successes, but in general there is only limited evidence that small-scale farming is changing at the scale needed to enhance food security of significant proportions of the population: farmers may be changing their practices, but these (mostly relatively small) changes are not always effective in enhancing their food security or resilience (Box 4).[65,66,67,68] With respect to larger or more

TABLE 2 Percentage of surveyed households assigned to four household types in 45 sites in five regions (6,300 households in total): regional means[69]

Region	No. of sites	Proportion of households of each type			
		Food insecure	Hanging in	Stepping up	Stepping out
East Africa	8	32.0	42.5	13.6	12.1
West Africa	5	13.8	69.6	11.0	5.6
Latin America	7	5.7	60.0	20.8	14.1
South Asia	22	9.2	57.7	16.5	16.7
South-East Asia	3	10.2	63.4	11.9	14.5
All	45	13.3	57.1	15.7	14.1

systemic adaptations, globally there are still relatively few (<50) solid, unequivocal examples in the literature of such climate-induced changes in both cropping and pastoralist households, and for most of these the eventual development outcomes are unclear.[70,71]

In searching for commonalities in the enabling environment among the CCAFS sites with similar proportions of household types, collective action at the community level coupled with appropriate climate information provision and the active participation of local agricultural and non-agricultural organizations was found to be associated with higher levels of food security. Broader questions remain as to the nature of an enabling environment that can promote sustainable livelihoods and agricultural growth. There are many examples illustrating the nature and importance of the enabling environment.

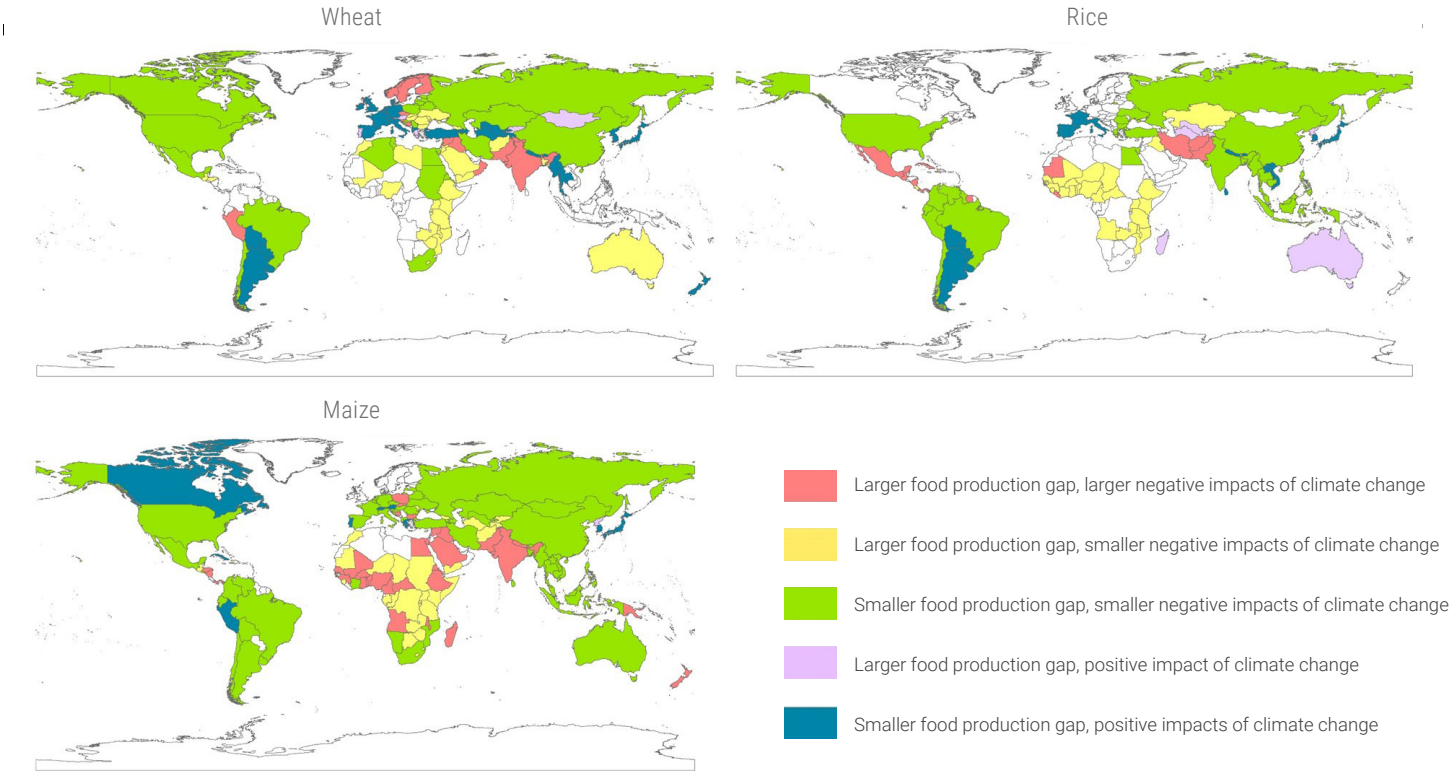
Case studies in villages in Zambia found substantial differences in the sources of agricultural growth and the resulting distributional effects, due to the complex interplay of national agricultural policy and price and climate volatility.[72] In a case study in rural India, unequal power relations between a company and farmers skewed the capture of benefits from contract farming towards the company, rendering participating households vulnerable to indebtedness and loss of autonomy over land and livelihood decisions.[73] Many pastoralists in Afar, in arid and semiarid Ethiopia, have moved to agro-pastoralism because of recurrent droughts and the government's sedentarization program. This is weakening indigenous institutions and cultural practices, and the likely impacts on future generations and Afar identity are very unclear.[74] The situation is the same for fisheries adaptation: on the one hand, institutional and legal barriers at the national level challenge adaptation objectives, but on the other, customary law can help to empower local communities to participate in resource management and the design and implementation of successful "bottom-up" adaptation strategies.[75] The fact is, to foster the changes needed in rural livelihoods at the scales required, a much stronger focus on more localized enabling environments will be needed if livelihood, national food security and adaptation goals are to be attained.

BOX 4 Hotspots of climate change and differentiated adaptation responses

The general picture of "some progress in adaptation but not enough" is confirmed by global studies. For example, a meta-analysis of the results from integrated assessment models shows that crop yield growth rates per year are already lagging; 1.2% per year globally, compared with the needed average of 1.8% per year.[76] National "hotspots", which combine production gaps (differences between supply and demand) with the severity of impacts of climate change on wheat, rice and maize, are shown in Figure 5.[77] For wheat, countries such as Ethiopia and South Africa show moderate production gaps with relatively small effects of climate change on production to the 2050s, once adaptation is factored in. These countries might then focus more on strengthening their food supply through trade and promoting incremental adaptation at local scales. In contrast, countries such as India, Pakistan and Peru have large wheat-consuming populations and need to address problems of likely substantial production gaps due to increasing demand coupled with large and negative climate change impacts on wheat yields. These countries may need to combine technology growth with transformative actions in terms of land use and high-yielding, stress-tolerant varieties, if they are to remain wheat secure from a self-sufficiency perspective. The situation is the same for maize in many countries of SSA and South Asia: increasing production gaps and substantial effects on maize productivity, highlighting the need for widescale transformative adaption in both commercial and small-scale sectors. But promoting adaptation and increasing resilience needs to be done in ways that are inclusive – a considerable challenge (see Box 2).

Adaptation has been occurring at other scales too, including national policy. Under the Paris Agreement, adopted at COP 21 and signed by 180 Parties in 2015, countries are in various stages of preparing, communicating and maintaining their nationally determined contributions (NDCs) to adaptation and greenhouse-gas mitigation. Many NDCs include agriculture as a priority sector for adaptation (and mitigation). Nevertheless, many of them fail to acknowledge drivers of deforestation and degradation from large-scale commercial agriculture productions.[78] There is also a growing number of National Adaptation Plans and Climate-Smart Agriculture policies and programmes. All these are helping to create a favourable policy environment for climate action, although successful implementation of these policies and programmes will depend on access to appropriate levels of finance (including national civil society so that finance gets to the front line) and effective governance and institutional mechanisms. Countries also need to focus on cross-sectoral coordination, given that many of the incentives for climate action in agriculture will come from other sectors such as energy, finance and

FIGURE 5 Hotspots of climate change based on assessments of impacts after adaptation on crop yield at country scale for the 2050s and the production gap (the difference between estimated cereal demand in 2050 and current cereal supply). Countries included only if the cropped area >10,000 ha.



Source: Aggarwal et al. (2019b).[79]

information and communications technology (ICT). As for other scales, the current status of adaptation nationally is difficult to assess, given the lack of commonly agreed frameworks to track adaptation.

There is also an adaptation agenda for agricultural service providers. Agribusinesses face several direct climate risks, with potential impacts on physical assets, production processes, depletion of natural resources, human resources and infrastructure. All these risks may affect business operations, profit and income. Schaer and Kuruppu (2018) provide several case studies of small and medium-scale enterprises adapting their business models and operations.[80] There is also growing interest in the role of large national and multinational corporations in adaptation, given their potential to finance climate-proofed projects, develop technologies and innovative solutions, and enhance the scale and cost-effectiveness of specific certain adaptation measures.[81]

4. Key elements and actors towards rural livelihood adaptation and transformation

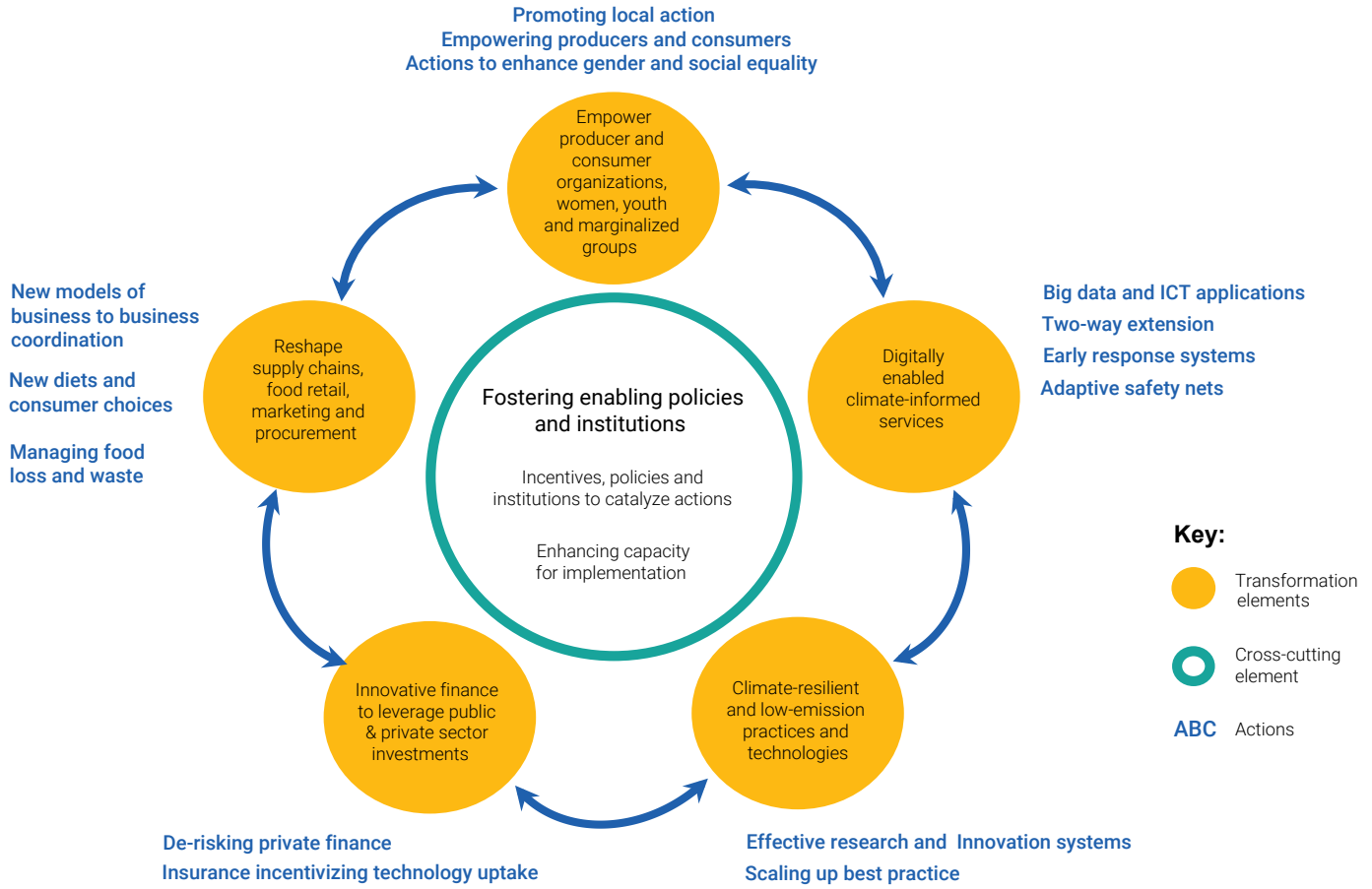
As indicated in previous sections, areas of poverty, food insecurity and extreme vulnerability remain entrenched, and current actions to adapt and build resilience are insufficient. Climate change and its associated extreme events, coupled with other changes operating in many places (such as demographic, urbanization, and socio-cultural change), will only add to the problems faced by rural dwellers. How can the global community respond to such urgent and daunting challenges? We envisage nothing short of a transformation of rural livelihoods, agriculture and the broader food system. Transformation here refers to a significant redistribution (at least a third) in the primary factors of production (land, labour, capital) or the outputs and outcomes of production, within a period of 10 years (modified from Vermuelen et al. 2018).[82] This includes significant changes to the structure of landholdings, technologies and the use of them, capabilities of women and men, and the distribution and dynamics of the population and labour force. Such a transformation will generate multiple benefits, including education, nutrition, health, water and sanitation, and empowerment of women and youth, translating into transformed and thriving rural livelihoods and communities.

If fundamental change is to be achieved, several elements will be needed in synergy, with less or more emphasis on particular elements depending on context. Actions to achieve this change will vary according to household heterogeneity and it is extremely unlikely that silver bullets exist, though technologies that are near-ready or in development could shift rural livelihoods, agriculture and food systems in unexpected ways in the coming decade, both positively and negatively.[83] Research will play a key role in advancing knowledge with respect to these technologies as well as in developing novel methods to insert these options into current food systems, and to better understanding what might affect their uptake to achieve transformation. Along with massive opportunities, there are massive risks too – in particular, ensuring that transformation leaves no-one behind and that all can benefit.

Drawing on Dinesh et al. (2018), we set out six priority key elements that are crucial to trigger truly transformational change in rural livelihoods, agriculture and food systems under climate change (Figure 6).[84] Each element involves a range of actions and actors, outlined below. Accelerating action and progress probably means that the six elements should not work in an isolated manner but on the contrary should all be part of the conditions that need to be in place in order for positive change to take place. Urgency is mostly needed; actions need to be implemented in the near term.

The proposed framework for transformation emerged from a process involving iterative discussions with various groups of stakeholders experts (Independent Steering Committee of CCAFS, Core Team of CCAFS, Panel of Experts for Transforming Food Systems under Climate Change, International Advisory Committee of the Fifth Global Science Conference on Climate Smart Agriculture, and Advisory Group on Transforming Global Food Systems under Climate Change, see Annex 1 for the list of members of these groups). Diverse versions of this framework have also been published in peer-review publications demonstrating the evolution of the line of thought behind the framework.[85,86,87]

FIGURE 6 Actions to transform rural livelihoods, agriculture and food systems under a changing climate.



Source: modified from Dinesh et al. 2018.[88]

EMPOWER PRODUCER AND CONSUMER ORGANIZATIONS, WOMEN, YOUTH AND MARGINALIZED GROUPS

Berdegué et al. (2015a) have clearly shown the importance of local organizations and their networking for achieving positive development outcomes (Section 1).[89] Strengthening producer and consumer organizations and their networking will be part of the efforts to drive transformation. An interesting example is Farmers for Climate Action, a movement of farmers, agricultural leaders and rural Australians working to ensure farmers are a key part of the solution to climate change.

Bottom-up approaches can help drive more effective implementation and scale up successful actions. Examples include a citizen science approach in Ethiopia whereby farmers do their own testing of new seed varieties; collective action as in the case of farmer-led greening in Tigray, previously an epicentre of famine and now largely food self-sufficient and greener than it has been during the last 150 years; swidden communities in Vietnam where local governance and social networks have contributed to maintain and enhance carbon stocks and therefore have enable their participation in schemes such as payments for environmental services (PES) and Reducing Emissions from Deforestation and Forest Degradation (REDD+) schemes; and Wefarm (wefarm.org), a farmer-to-farmer digital network with more than a million users across Kenya and Uganda, which can be accessed via internet or through text messaging on a mobile phone.

Farmer organizations, cooperatives and similar forms of collective action can reduce high transactions costs that can stimulate the participation of small-scale producers in markets.[90,91]

Understanding the specific needs and contexts under which rural dwellers forge their livelihoods (including the most marginalized groups) becomes an imperative for successfully building resilient rural livelihoods. This implies that the rural voice should be at the centre of the discussion when promoting adaptation pathways. Farmers' need to organize, network and improve access to information to negotiate with industry and have their voices heard in decision-making processes.

Capacity to adapt and management of threats amongst small-scale producers is often determined by personal networks which if not considered when designing strategies for adaptation to climate change could possibly exacerbate vulnerabilities.[92] Wise et al. (2014) and many other studies point to the importance of local institutions and networks in fostering climate action.[93] Social networks can enhance adaptation, especially at the community level, by building networks that are important for coping with extreme events.[94] Many of the technologies that could be implemented in the future will offer opportunities but also will pose threats to small-scale producers. Promoting joint actions by small-scale producers and their representatives through producer organizations, cooperatives, associations, enterprises, etc. will be key to enhance opportunities and reduce threats. One key challenge that must be acknowledged with respect to these representatives relates to their accountability. Sometimes, group leaders may not be true representatives of the groups that they are supposed to represent. It may thus be necessary to validate through participatory approaches that the real needs of the targeted groups are being addressed.[95]

Globally, women make up almost 50% of the agricultural labour force and in general, women are more likely than men to be working in the agriculture sector. Rural women are in fact playing an increasing role in small-scale production in many regions as a result of out-migration of males and high levels of dependence on local natural resources. Women also experience greater financial and resource constraints as well as less access to information (including agricultural extension), thereby affecting their resilience.[96] Food and nutrition security of women and girls is also likely to be compromised. Given this, it has been argued that women are more likely to be vulnerable to climate variability impacts and therefore climate change will likely exacerbate existing gender inequalities.

The increasing youth population in developing countries also poses challenges for climate adaptation. Seventy percent of African youth reside in rural areas and are employed in the agricultural sector.[97] Unemployment of 20%-45% of the youth population and engagement in livelihoods and enterprises which are affected by climate risks are widely identified as major challenges facing young people in developing countries.[98] Youth in rural areas derive their livelihoods from degraded natural resources and have limited access and control over productive assets, limited access to information and financial resources, and limited participation in household and farm decision-making, making them vulnerable to climate variability and weather-related shocks.[99]

Given the above-mentioned challenges, actions are needed to create conducive enabling environments that encourage producers, business owners, researchers, investors and policy makers to innovate in ways that promote gender equality and youth opportunities. Advancing gender equality and youth opportunities is a priority, given the very high rates of unemployment among young people, women's prominence among people living in poverty, their lack of access to resources and power, and the disproportionate agricultural labour burden that women face (Box 2). Moreover, advancing gender equality will generate positive outcomes for rural livelihoods, and food and nutrition security: e.g., it is estimated that if women had the same access to productive resources as men, the yields on their farms could increase by 20-30%. Researchers should also expand the scope of the analysis in relation to gender and climate change. According to Djoudi et al. (2016), in climate change studies, gender is mostly handled in a men-versus-women dichotomy and little attention has been paid to power and social and political relations.[100] These analyses are key to develop specific actions that can promote gender equality under climate change and that can enhance opportunities for adaptation.

REALIZE THE DIGITAL ERA IN RURAL LIVELIHOODS, AGRICULTURE AND FOOD SYSTEMS

The use of ICTs in agriculture and allied sectors is developing rapidly, though agriculture remains as the sector that is least digitalized. ICTs have a huge potential to revitalize rural livelihoods and agricultural extensions systems. Extension has long been facing decline and under-funding. Digitization promises to increase interaction among food system actors and amongst the rural community to improve efficiencies, reduce costs and enable better decisions in the context of climate change impacts, as well as contributing to disaster prevention and preparedness through early-warning systems of pest and disease outbreaks and extreme events (drought, flood, heatwave). If around 275-350 million farms gain access to mobile-based services by 2030, the total additional income generated would be in the range USD 100-200 billion driven by production increase and avoided losses.[101] The body of evidence is growing regularly, showing the ways in which digital innovations could improve the lives of rural people, and how the rapid growth of the internet and associated digital technologies such as mobile phones, have become a key element when it comes to providing the necessary information to farmers to promote transformative agricultural development.[102]

Examples of efficiency gains are already occurring. In 2014, Colombian rice farmers saved USD 3.5 million in input costs by preventing 1,800 hectares of rice crop from being lost. These savings were the result of following CIAT recommendations based on big data analysis that advised farmers not to plant during the usual dates.[103] This example saw national and international researchers combining with local producers' organizations and extension staff to generate the information needed and implement appropriate actions based on it. Another example is "Shamba Shape Up", a reality TV series about new farming technologies and practices that regularly reaches 5 million viewers in 3 countries in East Africa. It generated more than USD 24 million of productivity benefits during its first three series.[104] Shamba Shape Up is the brainchild of an organization dedicated to the use of media for education and development. Its effectiveness arises from the wide range of actors involved: funders, people working in civil society organizations and the commercial sector, and national and international researchers, as well as small-scale producers and both rural and urban consumers. Another interesting example is "Plantix", a free mobile crop advisory app that uses machine learning for automated image recognition to diagnose plant diseases, pests, and nutrient deficiencies. This app is facilitated by ICRISAT and so far has been downloaded more than 6.2 million times.[105] Digitalization also has the promise of promoting networking amongst rural persons, helping to facilitate empowerment.

SCALE UP EXISTING AND NEW CLIMATE-RESILIENT PRACTICES AND TECHNOLOGIES

If rural livelihoods, agriculture and food systems are to be transformed, existing climate-resilient practices and technologies will need to be scaled up, with researchers working alongside NGOs and the private sector to make much better use of the "back catalogue" of over 60 years of work on agricultural research for development in many lower-income countries. A range of relatively under-researched crops may have considerable substitution potential in different regions, as changing climates erode current crop suitability (Box 5), as well as contributing crop diversity that can have beneficial effects on household food self-sufficiency and food security (Box 6).

At the same time, new technologies will need to be developed that deal with the multiple and often interacting stresses such as drought, floods, heat, and pest-weed-disease burdens, as weather becomes increasingly unpredictable and variable. There are several near-ready technologies that may have considerable effects on different parts of the food system in the coming years. These include alternative protein sources for food and feed such as plant-based animal food substitutes, algae, seaweed and insects, new food storage technologies based on biodegradable and micro-organism coatings, and vertical farming.[106] As important is closing the yield gaps that currently exist (e.g., implementing best management practices), even in the absence of climate change. Landscape management will be fundamental to address the climate change challenge as is the case of less humid zones, where water management and governance, with solar micro-irrigation can constitute a promising area for joining up energy and agricultural agendas (Box 7). Globally 20% of cropland is irrigated, but only 5% in Africa. Xie et al. (2018) estimated that irrigated area in the drylands of sub-Saharan Africa (SSA) – home to about 425 million people

– can be expanded by 6-14 million hectares (nevertheless there is still debate in relation to the availability of water for irrigation), 84% of which is small-scale irrigation.[107] Greater focus on rural mechanization and post-harvest storage and processing relevant to small-scale producers can also be a boost to rural entrepreneurship.

BOX 5 "Orphan" crops under a changing climate

The "big three" (rice, maize and wheat) account for about 46% of the global cropped area and about 40% of calorie intake. These crops have received a great deal of attention in agricultural R&D. There are other crops that would benefit from much more R&D and market development attention, as some of them could be important substitution crops as climates change into the future (Table 3). They could also play a key role in on-farm crop diversification as an adaptation strategy. The table below shows a semi-quantitative evaluation of the potential role of different crops in climate change adaptation in different regions.

TABLE 3 Crops by region under a future climate: crop sensitivity to climate, where it is known (main body of table) and the crop's potential role in climate change adaptation (right-most column; "Unknown" indicates high uncertainty about the crop's role)

	Central Africa	Western Africa	Southern Africa	Eastern Africa	South Asia	South East Asia	West Asia - North Africa	LAC	Comfort level of analysis*	Sensitivity to climate**	Role in adaptation
Barley	Low	Low	Low	Medium	Low	Low	High	Low	Medium	Medium	Maintain as staple
Beans	High	Low	High	Medium	Low	Unknown	Unknown	Medium	High	High	Maintain as staple
Cassava	High	High	High	High	Medium	High	Low	High	High	Low	Important substitution crop
Chick Pea	Low	Low	Low	Low	High	Low	Medium	Low	Medium	Medium	Potential substitution crop
Cowpea	Medium	High	Medium	Medium	Medium	Low	Low	Low	Medium	Low	Potential substitution crop
Faba Bean	Unknown	Low	Unknown	Medium	Unknown	Unknown	Medium	Unknown	Low	Medium	Unknown
Groundnuts	Medium	High	Low	Medium	High	Low	Medium	Low	Medium	Medium	Unknown
Lentil	Low	Low	Low	Low	High	Low	High	Low	Low	Medium	Unknown
Maize	Medium	Medium	Medium	Medium	High	Medium	Medium	Medium	High	High	Maintain as staple
Millet	Medium	High	Medium	High	High	Low	Medium	Low	High	Low	Important substitution crop
Pigeon Pea	Medium	Low	Low	High	High	Low	Low	Low	Medium	Medium	Important substitution crop
Plantain/Banana	High	High	Medium	High	Medium	High	Low	Medium	High	Medium	Maintain as staple
Potato	Medium	Low	High	High	Medium	Low	Low	High	High	High	Maintain as staple
Rice	Low	Medium	Low	Medium	High	High	Low	High	High	Medium	Maintain as staple
Sorghum	High	High	High	Medium	High	Low	Low	Low	High	Low	Important substitution crop
Soybean	Medium	Medium	Medium	Medium	Unknown	Unknown	Low	Medium	Low	Medium	Maintain as staple
Sweet Potato	Medium	Unknown	Medium	Medium	Unknown	Low	Unknown	Unknown	Low	Medium	Important substitution crop
Wheat	Low	Low	Low	Low	Medium	Low	Medium	Low	Medium	High	Maintain as staple
Yams	Low	High	Low	Low	Low	Low	Low	Low	Medium	Low	Important substitution crop

** Comfort level of analysis: confidence level in the analysis*

*** Role in adaptation: how the crop may enhance adaptation. For "maintain as staple" crops, heat and drought traits will be important. For "substitution" crops, traits such as marketability / utilization, abiotic resistances and yield will be important.*

Sources: expert consultation led by Andrew Jarvis (CIAT); known impacts from http://ag-impacts.org/ estimatesearch/ and from Thornton and Cramer (2012).[108]

Inspiring examples of the successful scaling-up of new technology do exist, e.g., stress-tolerant maize varieties in Africa[iv]. Examples demonstrate that when the appropriate conditions are in place (e.g., right incentives and political will), new technologies can be successfully implemented at scale. Climate and weather information at a range of lead times can enable producers and value-chain actors to better manage climate-related risks throughout the agricultural calendar, enhance adaptation via agricultural diversification and enhance technology uptake.[110,111] Researchers are also working on a wide range of technologies that may have more transformational effects in the coming years: examples include vertical farming, plant-based meat and replacement protein sources for feed and food, including algae, seaweed and insects (some of these are already being marketed).

[iv] Farm trials have demonstrated that climate resilient maize varieties produce 20% more crop than current commercial varieties in low-yield environments, and double in severe stress environments, such as the El Niño event of 2015–16.[109]

INNOVATE FINANCE MODELS TO LEVERAGE PUBLIC AND PRIVATE SECTOR INVESTMENTS

Current levels of investment in climate action for agriculture and more broadly rural livelihoods will be insufficient to drive transformation. Innovative approaches

BOX 6 Farming diversity influences food security in Africa

Farmers in Africa have long adapted to climatic and other risks by diversifying their farming activities. The relationship between farming diversity and food security is complex. Using survey data from more than 28,000 households located in 18 African countries, it has been shown that households with greater farming diversity are more successful in meeting their consumption needs, up to a certain level of diversity per ha cropland. More diverse farming systems can contribute to household food security, although the relationship is influenced by other factors such as the market orientation of a household, livestock ownership, non-agricultural employment opportunities, and available land resources. The greatest opportunities for diversification of food crops, cash crops, and livestock in Africa are found in areas with 500–1,000 mm annual rainfall and 17%–22% annual rainfall variability. At least 43% of African cropland is found in areas without these characteristics, and the ability of agricultural systems in such places to respond to climate change may be hampered. A shift in research and policy towards agricultural diversification options in such areas may be necessary to support such households, though it should be noted that the scalability of practices based on agricultural diversity is heavily influenced by their relative value compared with other viable options for climate change adaptation.[112]

BOX 7 Growing solar power in India

India's Government is seeking to increase the use of solar energy up to 10% by 2020 by adding 100,000 megawatts of solar energy. Solar Power as a Remunerative Crop (SpaRC) is an on-going initiative led by IWMI that is connecting farmers to the energy market. Farmers participating in SPaRC are "growing solar power" as a remunerative "crop" by setting up solar panels. The energy generated by these farmers is being used for on-farm needs such as irrigation but at the same time is connecting farmers to markets via selling excess power back to the grid. This initiative is helping to accomplish the country's goals of addressing climate change, improving the sector's productivity, and achieving higher incomes for farmers.[113] In 2015, Ramanbhai Parmer, a small-scale farmer from Gujarat became the first "sunshine farmer" to sell energy back to the power grid from the solar panels that drive his water pump. Nationwide, IWMI estimates that approximately 11 million framers could benefit from this initiative.[114] Furthermore, Shah et al. (2018) argue that solar irrigation pumps has potential to unlock South Asia's perverse energy-groundwater nexus.[115] Nevertheless, there are some discussion in relation to the possibility of over-exploitation of ground water.[116]

will be needed to enhance investment flows, and these could include increasing private sector finance, impact investing and blended finance. At the macro level, enhanced investment flows can also result from more effective public investment in rural areas and agriculture to generate climate co-benefits – for example, by increasing the degree of climate smartness of the more than USD 600 billion in public agriculture support received by farmers every year[v]. This will require public investors to shift their focus towards de-risking and mobilizing private sector capital, and private investors to move away from the "business as usual" assessment of investment opportunities and focus on the long-term growth potential. The latter could provide robust arguments for private companies to comply with their commitments on sustainable practices (e.g., zero deforestation).

The public sector plays a decisive role in improving incentives and reducing transaction costs for the private sector. In the case of agriculture, for example, actions such as reducing commercial costs, enabling policy frameworks to access finance, improving regulatory regimes for markets, and providing public goods services that help access the market, such as food security frameworks and national quality infrastructure are key elements when it comes to attracting finance from the private sector. A key element that exemplifies how public sector legal and fiscal frameworks have helped to attract private investment is the establishment of national investment laws under the basis of good practices and the establishment of regulations by which competition can be effective in agriculture markets including strengthening antitrust regulations. An example of this is represented by Kenya, where the elimination of the powers of the holders to veto the license of new tea factories allowed the entry of new competitors and facilitated investments in the sector, allowing farmers to receive 70 % of the higher prices at the farm door.[117]

In addition to increasing the flow of capital at the macro level, financial instruments such as well-designed index insurance schemes can help protect producers' productive assets in the face of extreme climate events and promote the adoption of improved technologies and access to credit and market opportunities. Despite the large debate with respect to the implementation of index insurance and its ability to target small-scale producers, the introduction of indexed-based agricultural insurance in countries such as China, Mexico, Kenya and India shows much promise.[118]

As noted in Section 2 above, agricultural producers and agribusinesses have to address a range of climate risks, all of which may have an impact on operations and income. Their transactions costs may be too high owing to inefficient regulatory systems, for example. Many millions of rural small-scale producers and value chain actors are unable to access the loans, insurance and credit they need, in part because banks and other financial intermediaries see the risks of investing as being too high.[119] Some small-scale producers may be able to rely on social networks for small loans and start-up cash or to benefit from microfinance loans. Financial institutions will need to play a much bigger role in the future in facilitating access to loans, grants and seed capital. The latter includes building the business case for investing in small-scale producers (Box 8), but also the implementation of approaches such as Maximizing finance for development which intends to understand and propose actions in relation to the limited space for private sector activity. Innovative business models such as TULAA where farmers get access to information, inputs and finance, lowering risk massively and helping farmers make better-informed decisions are also part of the solution.[120]

There are several tools and mechanisms that can help small-scale producers to access loans, grants and seed capital, and more will be needed: soft loans or well-targeted subsidies, early-warning systems to better prepare for extreme weather events, funds coming from various sources de-risking large private sector investments. It is important to recognize that even though more investments are required, the current ones need to be used more efficiently. Pham et al. (2019) show that under some circumstances the problem is not having enough investment and funding for forest protection and adaptation activities.[121] The challenge is therefore to reduce inefficiencies born on high transaction costs due to lack of guidelines, overlapping in mandates, and unclear responsibilities amongst government agencies.

[v]Even though this number refers predominantly to OECD countries, it can be argued that what is needed is a change in the state of mind of policy makers so that the public sector uses its resources targeting resilience and sustainability goals.

BOX 8 Farmfit (case study taken from Millan et al. 2019)[122]

Farmfit works on innovative tools for smallholder service providers to increase the efficiency, profitability and viability of service delivery and thereby of local value chains. By analysing over 40 smallholder service provider models across 20 countries, Farmfit has built evidence on best practices and key drivers for resilient and profitable smallholder farming. This has resulted in the development of a benchmarking database and business support functions for companies and banks that are willing to engage sustainably with smallholders.

By building the business case for financial institutions and value chain actors, Farmfit aims to show private investors that a risky investment in smallholders can translate into meaningful financial returns and impact. For instance, Farmfit advices service providers on how to minimize the costs of servicing farmers, how to build a supportive enabling environment and how to improve access to a package of financial services, input provision and innovative technologies. The Farmfit Fund provides concessional finance and match-making services to co-fund the design, implementation, and monitoring and evaluation of scalable projects.

RESHAPE SUPPLY CHAINS, FOOD RETAIL, MARKETING AND PROCUREMENT

Food supply chains in many developing countries are going through rapid transformation. These changes can be harnessed to contribute to lasting food systems transformation at scale and can be harnessed to the benefit of rural populations. For example, small and medium enterprises are driving change in many countries, installing processing and cold chain facilities that may underpin future resilience to climate change, and that could contribute to rural employment. In addition, the installment of granaries and food storage from good production years to buffer during drought – and the interplay with post-harvest losses has demonstrated an important role for managing climate risk and enhancing adaptation.[123] Reductions in post-harvest losses and in food waste throughout the supply chain is another opportunity that has the potential to deliver on food security objectives, while creating new job opportunities. The effects of these changes could substantially reduce the demand burden on agricultural systems, delivering large reductions in the environmental impacts of farming and fishing. A further benefit might be increases in the profit margins, incomes, savings and resilience of small-scale producers, while also creating new off-farm job opportunities. There are many factors at work that may drive big changes in value chains in the future, which can provide considerable opportunities for rural populations. Markets are developing in new ways as urbanization increases, urban demand is increasing for supermarket and fast food, and as incomes rise, ethical and human health concerns could radically alter the demand for different types of food. The evolution of different agricultural value-chains and market configurations can provide big opportunities for rural producers (youth, particularly) to become entrepreneurs, provided that appropriate market, institutional and financial innovations can be harnessed to contribute an enabling environment for such activities. A key challenge in reshaping value chains in ways that are inclusive of actors at different scales will be the effective involvement of multiple stakeholders across the private, public and nonprofit sectors to identify interventions; and then to build the institutional capacity of industry associations, market intermediaries, researchers, governments, civil society organizations and grassroots groups, to implement them.[124]

FOSTER ENABLING POLICIES AND INSTITUTIONS

The sixth element of Figure 6 is placed in the centre given its crucial role for incentivizing actions in all the five elements discussed above. Promoting and achieving resilient and food- and nutritionally-secure rural livelihoods, imply new forms of strategic planning, involving not only individuals from the government and society, but interrelated and inclusive partnerships between the public and private sector. It is important to recognize the need for

an integrated approach where these enablers constitute the different pieces of a puzzle that if connected properly can make a huge contribution to building resilient rural livelihoods.

Policy initiatives are needed to create a conducive enabling environment that encourages innovation, investment and action. All the pathways discussed in the next section require a strong commitment from the policy side to deliver on the appropriate interventions that will make these pathways both feasible and attractive. Targeted policies are needed to develop secondary and tertiary industries in rural areas, but more importantly to support producers to exit rural agriculture and engage with urbanization. At the same time, policies are required in order to incentivize investments in training and re-skilling of the workforce so that producers can engage in new activities such as agro-processing and distribution and provision of farm inputs.

Brown et al. (2017) argued that "if trade restrictions proliferate, double exposure to both a rapidly changing climate and volatile markets will likely jeopardize the food security of millions".[125] As trade effectively diversifies risk on a global scale and as it means less volatility in food prices, free and open trade should be considered as an adaptation option. Therefore, policies that promote free trade can create a conducive enabling environment for adaptation to take place. Recent Free Trade Agreements or new initiatives such as FLEGT are being promoted and adopted in lower- and middle-income countries and could potentially change how agriculture and forestry sectors operate. Nevertheless, it is important to consider that these initiatives can also come with the risk of exclusion of small-scale producers, women and marginalized groups.

Since wrong policies can increase risks (e.g., under some circumstances, interventions promoting intensification can be inappropriate), the right policies and incentives need to be in place – not only agricultural policy but policy related to such issues as digital infrastructure, ease of doing business, landscape scale planning and land tenure, for example (Box 9 and 16). Creating enabling policies combined with institutional environments that facilitate regional and national policy implementation to build resilient and secure rural livelihoods are equally important. In this sense, an enabling environment to achieve transformation will include policies and institutions that generate the right incentives (e.g., the potential of realigning agricultural subsidies for fostering an enabling environment for more resilient agricultural systems), that open up opportunities for different adaptation pathways into the future, and that at the same time, foster a level playing field and ensure support for those left behind under appropriate right frameworks. Agricultural jobs are likely to change significantly in the future. Policy must anticipate and facilitate this fundamental change. Better targeting of public subsidies to incentivize private sector investment can be a game changer in financing the transformation of the rural world. World Bank studies demonstrate that subsidies often fail to promote resilient agricultural systems and lead to negative externalities including environmental damage; for example, environmental externalities arising from groundwater overdraft in the context of the power-irrigation nexus in parts of India.[126]

Strong, good governance is needed at multiple levels acknowledging that pathways for adaptation will vary according to type of producers and specific contexts. This governance needs to be transparent, equitable and inclusive in its processes and outcomes, and should consider multiple time frames. Trade-offs will happen most of the time and therefore the importance of understanding them spatially, temporally and across different groups in society is key.[127]

Power dynamics need to be addressed to promote resilient and food- and nutritionally-secure rural livelihoods. Understanding power dynamics of those stakeholders involved in the five different pathways described in Section 5 can help in the design of appropriate polices with adequate targets and to prioritize benefits to specific populations (most vulnerable, those deepest in poverty or consistently marginalized groups or landless). This could include supporting small-scale producers over larger, industrial farmers through targeted investments and extension. Other examples include establishing liveable wages and greater protections or workplace standards for landless farm workers or specifically targeting the poor with a package of support that includes training and microcredit as well as bundles of choices of appropriate technology to implement aquaculture and other small enterprise activities. In the face of unequal power dynamics, it is important to consider the risk of policy being set by those with power at the expense of those without. Policy processes need to engage a wide range of actors in rural areas, ensuring effective participation by marginalized groups.[128]

BOX 9 Improving livelihoods through communal tenure rights in the Maya Biosphere Reserve, Guatemala

The Maya Biosphere reserve is located in Guatemala and covers over 50% of Petén state, connecting to protected areas in Belize and Mexico, making it one of the largest areas of tropical forest north of the Amazon. Before the creation of the reserve, logging companies would harvest timber and implement other aggressive colonialization programmes, causing degradation of the ecosystem. Nevertheless, with the development of a long-term model, local communities were granted concessions to sustainably harvest wood and non-timber forest products, integrating livelihood and conservation policies and therefore allowing them to meet their economic needs by improving local production systems. This example demonstrates the possibility of protecting natural resources while creating jobs and increasing incomes for families that provide sustainable forest products.[129]

5. Vision for future: Differentiated pathways to adaptation and transformation

Context-specific adaptation actions that consider household heterogeneity at all scales need to be implemented. These actions need to be tailored to geography, socio-economic and cultural conditions, agro-ecology and to the needs of different social groups, who should have a say in shaping the adaptation actions. One single pathway, technology or solution set will not drive transformation. This section of the paper presents a discussion on potential pathways for adaptation and transformation and presents some successful examples of positive changes. It should be noted that trade-offs may exist in relation to each of these pathways. Research will need to play a key role to contribute to understanding and quantifying them so that appropriate interventions can be implemented to reduce these trade-offs. Furthermore, these pathways may be operating simultaneously in specific situations, depending on location and context.

The following represent plausible pathways (not all mutually exclusive and not exhaustive) that the global community should consider for promoting resilient and food and nutritionally secure rural livelihoods in the face of a changing climate: (1) increasing market integration and/or consolidating land so as to step up, (2) climate-informed shifts in the farming system so as to step up, (3) from landless to small-scale entrepreneurship, (4) climate-informed productive social safety nets and nature-based solutions for those least integrated into markets, and (5) exiting/reducing agriculture in the livelihood portfolio. These pathways were identified on the basis of a wide range of consultations with different experts, and are of course idealized – in the real world, they are they are complex, dynamic, continually unfolding and context specific.[130] Nevertheless, they do provide a useful mechanism for addressing at least some of the considerable heterogeneity of rural households in lower- and middle-income countries.

PATHWAY 1. INCREASING MARKET INTEGRATION AND/OR CONSOLIDATING LAND SO AS TO STEP UP

This pathway is based on better integrating small-scale producers into agricultural markets and intensified production. Producers would grow their share of the market so they can reinvest in technologies that further enhance their productivity and competitiveness, and in many places in the world close the yield gap. Some of the key features of this pathway include increased access to credit and risk-reducing options such as insurance, access to appropriate technology, and appropriate institutional and physical infrastructure. Irrigation can significantly reduce risk in drought-prone areas, but economic, management and environmental conditions need to be satisfied. In some cases, diversification is also occurring to spread risks and make new market linkages. Most of these features depend on developing tools and mechanisms so that financial institutions can contribute to facilitate access to loans, grants and seed capital as discussed in the previous section in relation to innovative finance models.

Evidence from eastern and southern Africa suggests that interventions aimed at facilitating small-scale organizations and improving access to better technologies and productive assets are key to stimulate small-scale market participation.[131] Farmer organizations, cooperatives and similar forms of collective action as well as ICTs can reduce high transactions costs that can stimulate the participation of small-scale producers in markets. Transaction costs can be reduced by farmer organizations taking over responsibilities such as input provision and distribution, bulking, grading, selling, processing and accessing agricultural extension.[132]

Although most small-scale producers do sell a part of what they produce, this can rarely be classified as commercialized agriculture. In many cases, such households sell products to generate cash to buy the food that they cannot grow themselves without generating any profit. Unless these small-scale producers gain access to more land to generate surpluses for sale or mange to become high-value niche producers, for example, they will not become commercial producers.

One way of achieving prosperity for these small-scale producers is through land consolidation (Box 10). This pathway involves land reforms with respect to tenure rights and land markets. An effective land market rental needs to be part of this pathway so that owners can get resources from renting their land and therefore could effectively remove themselves from direct involvement in agriculture. This pathway needs to be supported through increased access to credit, technology and infrastructure, though these would need to be a feature in facilitating many of the other pathways.[133] In some countries in LAC and SSA, for example, average farm sizes have continued to decrease through time, for reasons related to politics, culture and property rights. In such countries, the establishment of effective land rental markets will continue to face considerable challenges.

Processes around land consolidation and land rental markets should not exacerbate the negative impacts of land-use change. Potential threats to biodiversity, protected areas and carbon sinks such as forest and wetlands associated to land-use change need to be considered and avoided.

BOX 10 Consolidating land and improving local livelihoods in Romania

Mârşani is a commune located under the Romsilva Sadova forest district in Romania. This commune presents several challenges such as cumulative deforestation, overgrazing and sandy soils. The latter has led to widespread desertification and abandonment of lands in the region due to its low agricultural productivity. The Romanian government along with ALFO (Association of Local Forest Owners) has implemented a participatory land rehabilitation project, which seeks to redistribute these degraded lands amongst community members to help improve the environmental quality of the land and soil, along with creating economic benefits for local livelihoods. As a result, afforestation has taken place on 1100 ha of degraded land, benefiting over 980 owners who are receiving income from the sale of wood. In addition to stabilizing loose soils and adding productive value to the land, afforestation has also enhanced soil carbon stocks. This project has successfully tackled desertification, improved local livelihoods and contributed to climate change mitigation.[134]

PATHWAY 2. CLIMATE-INFORMED SHIFTS IN THE FARMING SYSTEM SO AS TO STEP UP

Under some circumstances, the most appropriate pathway to promote resilient and food secure rural livelihoods is through fundamentally changing the farming system, including shifting to practices such as agroecology and other types of less input-intensive agriculture, shifting from crops to livestock (Box 11), shifting to different livestock types (Box 12), or shifting to different crops (Box 13), for example. Climate change can be one of the most important triggers for these changes.

Decisions on appropriate changes to the farming system will need to be informed by the development of new technologies that deal with multiple and interacting stresses (drought, floods, heat, pests, and diseases) and with options for risk reduction such as index insurance schemes. Training and information about new options, strong policy support and investments to shift farming systems and access to credit and infrastructure will be key to successfully transforming to new farming systems.

BOX 11 Responding to climate change: shifting from crops to livestock in Peru

In the Langui region of Peru, rural livelihoods have transformed to a livestock-based economy in response to climate and market changes that have reduced farmers' harvests in recent years. Thus, these communities have reduced their activities for growing traditional staple crops and shifted to planting improved varieties of grasses for dairy production. This change has helped households to increase their resilience to climate changes and achieve more access to the growing dairy market.[135]

BOX 12 Responding to climate change: from livestock to camel production in northern Kenya

A study conducted in the semi-arid northern Kenya provided scientific evidence to support the observation that increasing climate variability is threatening reliance on cattle. Because of this, the Borana community decided to shift from cattle to camel production. Camels present biological and physiological adaptations that help them cope with harsh environmental conditions. They drink less water compared with other livestock species and are able to go for many days without water. Studies have shown that the volume of milk produced by camels is six times that produced by indigenous cattle found in the dry lands. Given the advantages that camel production presents in terms of food security, response to climate variability and income generation, the government of Kenya is incentivizing camel production and starting to address production constraints such as disease, raiding and competition from other livestock.[136]

BOX 13 Responding to climate change: from buckwheat and barley to vegetables and fruit trees in western Nepal

Climate change is a big threat to the biological diversity of the Himalaya, affecting the livelihoods of those living in remote villages, as it the case for the population of the village of Manang. Because of changes in the climate such as increasing temperatures and irregular precipitation patterns, the Manang people have shifted their agricultural practices, turning from traditional fields crops such as buckwheat and barley to the production of vegetables and fruit trees that are able to grow under a milder climate.[137]

PATHWAY 3. FROM LANDLESS TO SMALL-SCALE ENTREPRENEURSHIP (INCLUDING HIGHLY INTENSIVE PRODUCTION ON MICRO LANDHOLDINGS)

This pathway considers small-scale entrepreneurship as options for landless households and those with very small areas of land. One example is small-scale aquaculture which can substantially improve the livelihoods of poor, marginalized and vulnerable communities.[138] In Bangladesh, aquaculture interventions resulted in significant increases in incomes, savings, and frequency of fish consumption among participating landless households of ethnic minority communities (Box 14). Another option is indigenous "floating agriculture", which may have considerable potential for providing landless people in river basins with a livelihood during floods and long-term waterlogged conditions. This can provide processing and marketing livelihood alternatives for landless people, as well as food production options, provided that some of the challenges such as market access and pest and disease control can be addressed appropriately.[139] Box 15 outlines a case study of horticulture on riverbanks. All such interventions need to be highly tailored to the specific needs, circumstances and type of resources of the households.[140]

Another interesting option for landless communities is to raise livestock in areas close to cities. Because many livestock products are perishable and hard to move around, and because of limited refrigeration facilities in many parts of tropical Asia and Africa, this option is especially for those in close proximity to a good market. This option presents a two-dividend advantage: on the one hand, it can have a positive impact on childhood nutrition since studies have shown that children whose families own animals are healthier than children whose families do not; and on the other hand, raising animals can also allow families to make a good income by selling eggs and chickens, for example. Kenya presents interesting examples where peri-urban

BOX 14 Improving livelihoods: from landlessness and social marginalization to aquaculture in Bangladesh communities

During 2007-2009, aquaculture and related technologies were introduced to a total of 3594 resource-poor Adivasi households in Bangladesh. Baseline and end line surveys showed that household incomes of project participants rose significantly, because of increases in the proportion of households' aquaculture-related incomes: from 15% in 2007 to 30% in 2009. But the benefits of this transition were represented not only by an increase in incomes: the monthly frequency of fish, meat and egg consumption increased between 2007 and 2009 among project participants, showing positive results in relation to food and nutrition security among project participants.[141]

BOX 15 Improving livelihoods: from landlessness to pumpkins in riverbanks in Bangladesh

Riverbank erosion is one of the adverse consequences of climate change. In countries such as Bangladesh, this leads to the accumulation of sand during the monsoon in rivers and along river banks ("char" areas). Pumpkin cultivation has been introduced, which is well suited to the shifting, sandy soils of chars. A public-private collaboration has been assisting landless people to cultivate pumpkins, providing technical knowledge about pumpkin cultivation, identifying suitable sandbars, learning digging and composting techniques, and pumpkin seeding. Thousands of landless people, both men and women, are now engaged in pumpkin cultivation in Rangpur district and becoming financially solvent as a result. There is more work to do to establish markets and value chains for pumpkin, but this is a potential adaptation that is attracting both public and private sector attention, as it could be widely replicated in other char regions of the country.[142]

farming is incentivizing small-scale entrepreneurship through investment in technologies such as egg incubators to sell baby chicks to customers wanting to breed chickens.[143]

This pathway requires a strong commitment from local to national institutions to promote and incentivize small-scale entrepreneurship. Landless households need to be specifically targeted by national institutions with a package of support that includes training and microcredit as well as appropriate bundles of choices of technologies. Major constraints for this pathway include insufficient knowledge in relation to specific technologies at all levels and the limited capacity of national institutions to function as service providers.[144]

PATHWAY 4. CLIMATE-INFORMED PRODUCTIVE SOCIAL SAFETY NETS AND NATURE-BASED SOLUTIONS FOR THOSE LEAST INTEGRATED INTO MARKETS

Productive social safety nets (PSSN) can protect the livelihoods of chronically vulnerable and food-insecure populations from the increasing frequency and intensity of extreme climate events. Well-designed PSSN programs have proven potential to reduce costly household coping strategies in the face of climate shocks. Adaptive innovations, such as integration with credit, production inputs, agricultural extension and risk finance, increase the responsiveness of PSSN programs to climate shocks (Box 16).[145] As mentioned in the previous section, social networks can play a significant role in enhancing resilience, and therefore building networks can constitute an efficient safety net for coping with extreme events.

Cash transfer income tools such as the Universal Basic Income (UBI, giving every member of society a regular cash transfer income) constitute interesting examples to promote this pathway. India, Finland, Brazil, Kenya and the Netherlands are trialling (or have trialled) this instrument as one of the possible ways to reduce the vulnerability of producers to food price volatility and climate phenomena. The rationale is that a basic income given individually, unconditionally and automatically to all food producers could enhance the bargaining power of producers vis-à-vis other actors along the value chain such as commodity buyers, food processors and retailers. It could also provide a market closer to home for the products of small-scale market producers given that there would be more disposable income in poorer areas. In the long term this could lead to financially viable smaller farms. UBI could also have a positive impact on small-scale subsistence producers by allowing them to continue growing food for subsistence without having to generate excess production to generate cash income. It could thus lead to improved food security.[146]

BOX 16 Large-scale "greening" in Tigray, north-eastern Ethiopia

Characterized by semi-arid conditions with high rainfall variability, steep slopes and shallow soils, Tigray (north-eastern Ethiopia) was the epicentre of the 1980s famine and faced another famine less than a decade ago. The landscape has been transformed and the area is now largely food self-sufficient. The region is now greener than it has been for 150 years. Keys to success have been collective action and local leadership, which have helped mobilize every able-bodied man and woman over 18 years to contribute at least 20 days of community labour to environmental rehabilitation – building stone terraces and other soil and water retention structures, digging wells and planting trees, for example. Free grazing and firewood collection have been heavily controlled, allowing natural regeneration of these exclosures, groundwater recharge in valleys and degraded land being turned into productive farmland. Over one million hectares of degraded land have been restored in East and Central Tigray alone and the region went from 40 hectares of irrigated land in the 1990s to 40,000 hectares today, allowing farmers to produce higher-value vegetables and fruits even in drought years. With appropriate policies and incentives, collective activities around productive social safety nets can lead to change happening both rapidly and at large scale.[147] Some of the success factors associated with this example are discussed in Vermeulen et al. (2018).[148]

Unlike pathway #1, households in this category are unlikely to invest in significant external inputs, so attention needs to be given to low-input systems, nature-based solutions, and ecosystem and community-based adaptation. This would include techniques to improve soil and water conservation, use of drought-adapted varieties and breeds and agroforestry. Of equal importance would be to include indigenous knowledge in these initiatives, as it constitutes an invaluable basis for developing adaptation and natural resource management strategies in response to climate change.

Biodiversity, ecosystems, and their services have become increasingly relevant to promote the consolidation of resilient rural livelihoods and could become an appropriate pathway for some small-scale producers (Box 17). Approaches such as Payments for Environmental Services or Ecosystem-Based Adaptation (EbA) are based on the premise that the use of biodiversity and ecosystem services as part of an overall adaptation strategy can help people to adapt to the effects of climate change. According to IUCN healthy ecosystems can provide many benefits to local rural communities including firewood, medicines, shelter, clean water and food while at the same time they can secure rural communities from weather extreme events such as storm surges. On the other hand, biodiverse forests can protect rural lands from erosion and landslides. Some examples of EbA practices include sustainable agriculture, integrated water resource management and sustainable forest management. Recognition and uptake of local and traditional knowledge and understanding of the needs of vulnerable rural communities such as women and youth are key components of successful ecosystem-based approaches. EbA can and should be carried out in a community-based way. Community-Based Adaptation (CbA) is a people centred and holistic approach that focuses on four strategies: building adaptive capacity, supporting resilient livelihoods, reducing disaster risk and addressing the underlying (structural, social, economic and political) causes of vulnerability. EbA and CbA complement each other and can constitute a robust process for consolidating resilient rural livelihoods. In a similar way, developing strong business cases for conservation and for understanding the value of communities as promoters of adaptation pathways will be key to bring these approaches to scale.

BOX 17 The Quesungual system: sustainable land management changing lives[149]

One of the most exciting examples of protecting ecosystems as a way to promote resilient rural livelihoods can be found in Lempira in the southwestern part of Honduras. Before implementing the Quesungual system, most farmers in this region were using the slash-and-burn method of farming. As a consequence, crops were grown only for one to three years until the yields fell because of less moisture and fertility. Since these plots were not useful any more, farmers had to move to new plots and clear, burn and plant all over again observing the same results as in previous plots. This unsustainable practice was increasingly affecting resources and food security in the region.

Small-scale farmers in Lempira came to understand that this practice was working against their interests and decided to implement the Quesungual agroforestry farming system, which was tailored to the biophysical and socio-economic conditions of their region. Through Quesungual farmers started to manage vegetation clearing it by hand and trees were preserved as providers of fruit, firewood, wood for furniture, and to provide a fresh microenvironment for their crops. As a result of the implementation of these very simple practices, small-scale farmers in the region started to evidence an increased in production, resilience and sustainability. Yields were almost doubling, less labor was required, the soil was retaining moisture better and humidity levels were improving enabling crops to respond better to regular droughts and minimizing the risk of landslides and erosion.

In this way, small-scale farmers in Lempira were able to transition from a very unsustainable way of doing farming into a new system where farmers were getting more for less and at the same time were eating better with more nutritious foods.

PATHWAY 5. EXITING/REDUCING AGRICULTURE IN THE LIVELIHOOD PORTFOLIO

Under some circumstances and amongst some households, agriculture will not be the answer to achieve resilient rural livelihoods. A set of opportunities lies between completely exiting agriculture and reducing its weight in rural activities. For exiting agricultural production, it is important to consider the ability of different types of producers to generate enough income to ensure a meaningful livelihood. In addition, climate change may worsen the situation making farming non-viable in many areas, especially for coastal communities where sea level rise will increasingly bring adverse impacts such as submergence, coastal flooding and erosion and for semi-arid regions where cropping is already marginal and will become increasingly so.[150,151] In such cases, the only solution available to farmers might be transitioning out of agriculture and seeking alternative livelihoods through migration. Today the total number of international migrants, including those displaced by climate-related natural disasters, is 40 percent higher than in 2000, with numbers expected to exceed 400 million by 2050.[152]

The Sendai Framework for Disaster Risk Reduction, the Paris Agreement and the 2030 Agenda for Sustainable Development have all highlighted the need for urgent action to address climate change's role as a driver of migration. It is imperative to identify where migration is a valid climate change adaptation measure and where such large-scale migration is likely to occur; and to develop the practical policy measures needed to support the future livelihoods of such migrants (Box 18). This is especially relevant considering the high levels of youth unemployment in many rural regions and the current relative lack of growth in off-farm opportunities, particularly in SSA. Thus, policies, resources and measures for exiting agriculture and supporting future livelihoods of migrants should be part of any climate and agricultural transformation strategy.

Small-scale producers often already rely on multiple income sources. Another option for achieving resilient rural livelihoods is through reducing agriculture in the livelihoods portfolio and a plausible pathway in some places will be to develop more secondary and tertiary economic opportunities in rural areas. Examples of the latter could include improving the post-harvest value chain and other ancillary activities such as agro-processing,

BOX 18 Adapting through migration in the upper delta of the Mekong river

Over the past 20-30 years, the upper delta of the Mekong River in Vietnam has presented several changes with respect to rainfall patterns. The area is flooded annually, which enriches the soil but also poses a threat to the communities when floods are higher than usual. Nevertheless and despite an increase in rainfall, flood levels have decreased over the past 20-30 years given to changing rainfall patterns and water retention upstream of the Mekong River. Results from a survey performed in three villages in the region revealed that the vast majority of the population believes that rice yields have been negatively affected by changing rainfall patterns and changing flood regimes. Out-migration in these three villages has increased rapidly, particularly in the past 10 years. Some 60% of the households surveyed declared that at least one current member had migration experience. Interestingly enough, most migrants who left for long periods moved to places outside the Mekong Delta region, going mostly to industrial zones. According to this experience, migration has been a common alternative to these communities by which poor and landless households have used migrant savings and remittances to buy food and pay back loans. In the same manner, they have used this money to implement in situ adaptation activities such as diversification into non-farm activities, community based saving schemes, raising the foundation of houses, and investments in children's education so that they can find a better future working in economic sectors that are less sensitive to weather variations. This example highlights the importance of remittances in these migration processes as a mean of improving the financial situation of the households. In the case of the upper delta of the Mekong River, remittances improved the quality of the communities' livelihoods, became a source for starting new micro-scale projects, and allowed parents to pay for high quality education for their children.[153]

and distribution and provision of farm inputs. In some situations, there will be opportunities around digital agriculture (see previous section), tourism, marketing of artisanal and non-timber forest products, and other services for rural populations such as energy farming. Engaging in these kinds of activities can increase household incomes and help boost agricultural productivity by increasing the ability to purchase agricultural inputs.

Development policies and programs can generate incentives and capacities for rural households to participate in non-farm activities. Investments in general education and specific skills for non-farm activities, through the use of media for education (as in the example of "Shamba Shape Up") or through the establishment of technology information centers in rural areas to help to identify promising opportunities will be key to generate these incentives and capacities.

Table 4 presents a summary of the key interventions needed for each one of the pathways presented in this section, considering the relation between these interventions and the transformation elements presented in section 4.

TABLE 4 Pathways and interventions needed, with the transformation elements indicated (E, empowerment; D, digitalization; T, technologies and practices; F, financial model innovation; S, supply chain reshaping; P, policy and institutional enablers)

Pathway	Interventions for each pathway and the elements addressed
#1. Increasing market integration and/or consolidating land so as to step up	• Increased access to credit, technology, and infrastructure F, T, D, P, E • Promote risk reducing options D, S, T, P • Implement tenure reforms, enhance land rental markets P, F, E, T • Strengthen farming organizations, cooperatives and similar forms of collective action E, F, P • Farmers' to organize, network and improve access to information to negotiate with industry and have their voices heard in decision-making processes E, D, P
#2. Climate-informed shifts in the farming system so as to step up	• Development of new technologies that deal with multiple and interacting stresses T • Training and information about new options E • Strong policy support and investments to shift farming systems P, F, E • Access to credit, technology, and infrastructure F, T, D, E • Promote risk reducing options D, S, T
#3. From landless to small-scale entrepreneurship	• Strong policy support and investments to incentivize new farming systems and innovative methods of production, such as urban farming and floating agriculture P, S, T, E • Provide training, microcredit, and appropriate bundles of choices of technologies E, F, T
#4. Climate-informed productive social safety nets and nature-based solutions for those least integrated into markets	• Strong policy support for social safety nets, for schemes for payments for environmental services and for ecosystems conservation P, F • Implement cash transfer income tools F • Capacity building for implementing ecosystem and community based adaptation approaches E • Development of business cases for conservation D, P, F • Strengthen farming organizations, cooperatives and similar forms of collective action E, F, P • Farmers' to organize, network and improve access to information to negotiate with industry and have their voices heard in decision-making processes E, D, P
#5. Exiting/reducing agriculture in the livelihood portfolio	• Develop policy measures to support future livelihoods of migrants P • Implement policies to develop secondary and tertiary industries in rural areas P, F • Develop policies and investments in education and specific skills for non-farm activities P, E • Use of media for education and establishment of technology information centres to identify promising off-farm opportunities E, D • Enhance opportunities around digital agriculture E, D

6. Conclusion: the way forward

Rural livelihoods in lower- and middle-income countries face big challenges in the lead-up to 2030 (as the target year for achievement of the SDGs) because of a raft of drivers, including demographic, climate and technological change. This paper has highlighted several key issues affecting adaptation action. First, rural transformation is already happening in many places, but at different rates in different places, and in different directions. Understanding this complexity is critical, as different "directions of travel" imply different interventions for adaptation in different contexts. Different directions of travel may also affect the development outcomes that these transitions give rise to. Therefore, it is imperative to increase the understanding of how risks may affect these transformation processes and the factors influencing these directions of travel. Several examples of positive transitions have been described above; more are needed so that the lessons can by synthesized and replicated elsewhere. Second, rural small-scale producers will persist as key food providers and agents of change for a while yet. The industrialization trajectory seen in other parts of the world in the nineteenth and twentieth centuries generated mass employment opportunities, but the pace of technological change in industry generally makes this trajectory unlikely in many parts of sub-Saharan Africa (and possibly Asia too) in the foreseeable future. It seems that Africa will need to navigate its own course – there will be plenty of uncertainty, doubtless, but plenty of potential too. Third, there has certainly been some progress in small-scale producers' adaptation, but it would appear to be insufficient for the challenges that lie ahead. It has long been recognized that the success or otherwise of pro-poor agricultural technologies and practices in leading to desired development outcomes depends heavily on local context. It is increasingly apparent that the enabling environment within which small-scale producers can thrive is also context specific because this environment is characterized by drivers at multiple levels: national and international policy as well as the local organizational landscape, for example. Fourth, adaptation actions, as envisaged in this paper link to many other areas where action is required, thus adaptation actions can also, and need to, address poverty, nutrition and employment challenges.

Daunting food security challenges lie ahead. But some suggested actions for moving forward are listed in Table 5 in relation to the six transformation elements discussed in Section 4 and the interventions highlighted in Table 4. Taken together, Tables 4 and 5 outline specific actions and interventions that can contribute to rural transformation: in Table 4, using the lens of the five pathways described in Section 5 above; and in Table 5, using the lens of the six elements of the transformation framework presented in Figure 6.

The underlying hypothesis of this paper, outlined in Section 4 above, is that if the severe challenges around food are to be overcome, then nothing short of a transformation of rural livelihoods, agriculture and food systems is required. Such transformation will have huge implications for rural populations; managing these implications in the pursuit of desired development outcomes will require a range of elements to be operating in synergy, with less or more emphasis on particular elements depending on context. This underlines both the importance and value of understanding transformation processes at different scales and the necessity of wide stakeholder participation and social inclusion in the pursuit of these development goals.

TABLE 5 Examples of actions needed to address the six transformation elements. These combine the interventions shown in Table 4 under each pathway with actions outlined in Section 4

Elements	Examples of actions
Empower producer and consumer organizations, women, youth and marginalized groups	• Strengthen producer and consumer organizations and their networking • Use bottom-up approaches to help drive more effective implementation and scale up successful actions • Promote projects where farmers do their own testing of new seed varieties • Incentivize farmer-to-farmer digital networks • Develop and implement attractive business cases (considering opportunities for the youth) with the private sector supported by national and international climate finance • Create conducive enabling environments that encourage producers, business owners, researchers, investors and policy makers to innovate in ways that promote gender equality and youth opportunities
Realize the digital era in rural livelihoods, agriculture and food systems	• Promote the digitization of rural areas, agriculture and food systems • Increase the access of farmers to mobile-based services • Use big data analysis for agriculture advising • Increase the use of media for education and development • Enhance the use of ICTs to improve tracking of adaptation progress at different scales
Scale up existing and new climate-resilient practices and technologies	• Mine the back catalogue of work on agricultural research for development to develop compendia of the interventions that are known to work where and why • Determine if we have the food and feed crop varieties that will maintain / enhance productivity in a warmer, more climate-variable future • Develop new technologies that deal with the multiple and often interacting stresses such as drought, floods, heat, and pest-weed-disease burdens, as weather becomes increasingly unpredictable and variable • Invest in developing technologies that may have transformational effects in the coming years, such as vertical farming, plant-based meat and replacement protein sources for feed and food, including algae, seaweed and insects, and new food storage technologies based on biodegradable and micro-organism coatings

Table 5 continued

Elements	Examples of actions
Innovate finance models to leverage public and private sector investments	• Strengthen incentive structures for multi- and trans-disciplinary teams and innovative partnership models • Promote more effective public investment in agriculture to generate climate co-benefits • Promote and incentivize the use of well-designed index insurance schemes • Develop tools and mechanisms so that financial institutions can contribute to facilitate access to loans, grants and seed capital (e.g., soft loans or well-targeted subsidies, early-warning systems to better prepare for extreme weather events, and heavy involvement of the private sector in providing financial inputs)
Reshape supply chains, food retail, marketing and procurement	• Promote the installation by small and medium enterprises of processing and cold chain facilities that may underpin future resilience to climate change • Incentivize reductions in post-harvest losses and in food waste throughout the supply chain • Build the institutional capacity of industry associations, market intermediaries, researchers, governments, civil society organizations and grassroots groups, to implement in order to reshape value chains towards sustainability
Foster enabling policies and institutions	• Develop and implement targeted policies to develop secondary and tertiary industries in rural areas, and to support producers to exit rural agriculture and engage with urbanization • Develop and implement actions and policies to incentivize investments in training and re-skilling of the workforce so that producers can engage in new activities such as agro-processing, and distribution and provision of farm inputs • Develop and implement policies that go beyond agriculture and that consider issues such as digital infrastructure, ease of doing business, land tenure • Develop and implement actions and policies that foster a level playing field and that ensure support for those left behind (e.g., support for small-scale producers over larger, industrial farmers through targeted investments and extension; establishing liveable wages; universal basic oncome; workplace standards for landless farm workers; targeting the poor with a package of support that includes training and microcredit and bundles of choices of appropriate technology to implement aquaculture activities) • Develop and implement policies that provide the right incentives so that the private sector invests in rural transformation (e.g., reducing transaction costs, better targeting public subsidies, realigning public support to make agricultural systems more climate resilient).

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ANNEX 1

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- Inger Andersen: Executive Director: United Nations Environment Programme (UNEP)
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The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) seeks to address the increasing challenge of global warming and declining food security on agricultural practices, policies and measures through strategic, broad-based global partnerships. CCAFS brings together some of the world's best researchers in agricultural science, climate science, environmental and social sciences to identify and address the most important interactions, synergies and trade-offs between climate change and agriculture. CCAFS is carried out with support from the CGIAR Trust Fund and through bilateral funding agreements. For details please visit https://ccafs.cgiar.org/donors.

Madras School of Economics (MSE) is an institution of higher education in economics, located in Chennai, India. MSE aims to become an internationally recognized Centre of Excellence in economic studies, attracting the best of students and teachers from different parts of the country.

CATIE, as an international entity with a unique combination of science, graduate education and innovation for development, has its bases well-grounded and a clear action plan for creating professionals with a distinct perspective who can also contribute to the sustainable growth of the communities.

The African Climate and Development Initiative (ACDI) achieved formal status as a university institute in 2018. Viewed as one of the continent's foremost climate change institutes, ACDI provides a platform for University of Cape Town's and The African Research Universities Alliance's collective response to the challenge of climate change by coordinating and centralizing resources to enable inter- and transdisciplinary research, teaching and learning in the areas of climate change and sustainable development across Africa and beyond.

ABOUT THE GLOBAL COMMISSION ON ADAPTATION

The Global Commission on Adaptation seeks to accelerate adaptation action and support by elevating the political visibility of adaptation and focusing on concrete solutions. It is convened by 20 countries and guided by more than 30 Commissioners, and co-managed by the Global Center on Adaptation and World Resources Institute.