Chapter III

Bringing inequalities to the forefront of climate assessments

Key messages

- Natural and social scientists are addressing the complexity of climate impacts and policies using integrated climate impact assessments. They integrate different models to capture the multiple interlinkages across the environmental, economic and social dimensions of development as they relate to climate. This generates a cascade of scenarios on the potential impacts of climate projections and policy options for addressing them within a well-structured science-policy interface.
- The focus of these assessments needs to be sharpened in order to broaden the analysis to include both policy options for climate adaptation and resilience and a broader analysis of the economic and financial feasibility of those options. Importantly, the analysis of inequalities should be at the forefront.
- Existing modelling frameworks are useful for addressing inequalities from different perspectives by: analysing impacts on livelihoods that rely on climate-sensitive natural resources; addressing income distribution on the basis of ownership and employment of production factors; assessing options for building human capital and access to public services; and identifying the vulnerability of households based on their socioeconomic characteristics. The analysis is improved considerably if stakeholders participate in designing and developing an understanding of the results.
- Countries have much to gain from enhancing capacities to develop and use integrated climate impact assessments through which they gather a robust range of estimates of impacts and policy options for informed policy decision-making. Improved communication of results and engagement of stakeholders in the discussion of policy options derived from integrated assessments will improve collaboration and strengthen governance.

[Integrated Assessment Models combine] key elements of biophysical and economic systems into one integrated system. They provide convenient frameworks to combine knowledge from a wide range of disciplines. These models strip down the laws of nature and human behaviour to their essentials to depict how increased GHGs in the atmosphere affect temperature, and how temperature change causes quantifiable economic losses.

IPCC, *Climate Change 2001: Mitigation*
Contribution of Working Group III to the
Third Assessment Report of the
Intergovernmental Panel on Climate Change,
p. 490, sect. 7.6.4

Introduction

It is important to bring together the different methodologies available to support integrated assessments in informing sustainable development policy

One of the major challenges in the implementation of the 2030 Agenda for Sustainable Development[1] is integrating the various facets of the environment into development policies. Based on the experience of the past decades, there is better understanding of the links between the economic and social dimensions of development. It took several years and improved data and analytical capacities to move away from the narrow focus on economic growth as the main source of development. There is a better understanding of the characteristics of households and the sources of people's vulnerability to economic shocks. The policy frameworks that enhance consistency between economic and social policies have also been strengthened. Environmental concerns, in general, and the impact of climate hazards on people's livelihoods, in particular, need to be better understood. Addressing these challenges requires improved policy frameworks and analytical capacities to assist in the design and implementation of coherent policies across the economic, social and environmental dimensions of development. More broadly, and as is consistent with the 2030 Agenda, it is important to strengthen the science-policy interface and the development of strong evidence-based instruments so as to support policymakers in promoting poverty eradication and sustainable development.[2] It is thus important to bring together the different methodologies available to support integrated assessments of development challenges, including building climate resilience.

Consideration of options for achieving climate resilience for sustainable development is a complex task. It requires good information systems which provide the data and statistics necessary to identify people at risk in their (often very local) geographical contexts. It also requires improved integrated assessments of possible impacts of climate hazards on people and their livelihoods, including sound analysis of policy options for building resilience in anticipation of such impacts or, when they occur, for providing assistance in coping with and recovering from them. These assessments, in turn, require knowledge across disciplines belonging to the natural and social sciences, as well as local knowledge; in fact, they extend beyond the traditional expertise of the development community and the scientists working within their own disciplines.

Integrated assessments of climate impacts and policies are informing international climate discussions and policymaking...

Faced with such complexity, the international community of natural and social scientists has adopted an integrated approach to climate impact assessments. This approach seeks to generate scenarios on potential impacts of climate projections and the policies available to address them, for the world as a whole and for smaller geographical levels.

Scenarios from integrated climate impact assessments rely on various models to evaluate impacts of climate change on different aspects of development. Model-based analyses have been informing international climate discussions and feature prominently among the tools used in assessment reports of the Intergovernmental Panel on Climate Change (IPCC) to support conclusions and recommendations (see, e.g., the IPCC Fifth Assessment Report, 2014). Scenarios from these assessments are also being used by countries to develop narrative storylines which help decision makers plan policy interventions for reducing adverse impacts arising from a changing climate.

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1 General Assembly resolution 70/1.

2 Ibid., para. 83.

At the same time, the members of the international community of scientists and local researchers developing integrated climate impact assessments have taken note of the limitations of the approach and, not least, of the uncertainty surrounding the results obtained from model-based scenarios. The climate projections upon which assessments rely are themselves uncertain. There is also an awareness that since even the most sophisticated models represent an imperfect simplification of complex realities, their results need to be utilized with caution. These imperfections notwithstanding, integrated climate impact assessments seem to be the most reliable mechanism available for establishing a range of plausible impact scenarios which are critical for achieving an understanding of the magnitude of potential risks and policy responses. Other approaches to assessments that are more qualitative in nature—and sometimes even entirely theoretical—cannot fully replace the key functionality of integrated climate impact assessments (i.e., numerical estimation across the different dimensions of development), although they are a highly important complement. In fact, new methodologies designed to incorporate systematically the opinions of relevant stakeholders in modelling specifications, including scenario-building, are helping to improve the interpretation of, and reduce the uncertainty surrounding, the outcomes of climate impact assessments. This practice can be critical in helping to build consensus around development priorities and strengthen policy coordination and the governance of decision-making processes.

...through helping to establish a range of plausible impact scenarios, which is critical for understanding the magnitude of risks and policy responses

Through its holistic character, the 2030 Agenda for Sustainable Development is increasing the demand for integrated assessment approaches with the engagement of stakeholders, as the basis for coherent policy formulation. However, the use of integrated impact assessments as a tool for policymaking is in its infancy in developing countries and needs to be nurtured through capacity-building. In many countries, there are data and technical capacity constraints on the use of modelling tools as part of routine policymaking assessments. Those countries therefore rely on partial quantitative assessments, qualitative evaluations or value judgments. While these partial approaches are useful and necessary, they do not fully capture the interlinkages among the different dimensions of development. Developing capacity to design and use integrated impact assessments will enable them to provide the policy dialogue with scientific evidence within the margin of uncertainty surrounding these methodologies.

The use of integrated impact assessments as a tool for policymaking in developing countries needs to be nurtured through capacity-building

In strengthening the capacity of countries to use integrated impact assessments for climate resilience, it is necessary to sharpen the focus of analysis in various areas, three of which are discussed in the present chapter. In this regard:

Sharpening the development focus of assessments and bringing inequalities to the forefront of the analysis enhances their relevance in decision-making

- It is important to expand the narrow focus on long-term climate change and mitigation to include assessments on the impact of climate hazards that are caused by climate variability and extreme weather events, and expand the assessment of policy questions to include adaptation and resilience.
- There is a need to expand beyond a limited accounting of the costs and benefits of single climate policies by deepening the analysis of the broader economic and financial feasibility of development policies for climate resilience.
- Importantly, integrated climate impact assessments have not systematically addressed the way in which inequalities exacerbate vulnerability to climate hazards and the policy options that would contribute to addressing structural inequalities with a view to building climate resilience.

Without a doubt, it is of critical importance for data and statistical capacity to be improved before we can even begin to think about the construction of integrated climate impact assessments, particularly in developing countries, and this challenge will be discussed in depth in chapter V. In addressing the three areas of improvement listed above, this chapter focuses attention on the need to bring inequalities to the forefront of analysis. In doing so, it examines different ways in which existing modelling frameworks can be used to trace effects of climate hazards on vulnerable populations and assess policy options for addressing different sources of inequality. Through improvements in these three areas (as well as in data and statistical capacity), integrated climate impact assessments can respond to such questions as:

- What are the potential impacts of climate hazards on livelihoods? Do existing inequalities exacerbate these impacts or the risk of experiencing them? What are the dimensions of inequality that make people vulnerable to climate hazards? Are inequalities aggravated by climate hazards?
- Which are the policy options that, by addressing existing inequalities, contribute to building climate resilience? Are these policies economically feasible in view of the challenging financial gaps, not least in the area of adaptation?

The following section describes the integrated approach to climate impact assessments in the form in which it is mostly applied in practice, focusing on the analytical steps it entails and its strengths and weaknesses. This description lays the ground work for achieving an understanding, in the subsequent section, of the ways in which modelling frameworks are used to explore different dimensions of inequality. The final section sets out the key challenges going forward to making the integrated approach to climate impact assessments more accessible and more applicable, particularly in developing countries where the urgency of adaptation and building resilience to climate hazards is greatest.

The integrated approach to climate impact assessments

The different models that are featured at present in integrated climate impact assessments can be used to bring inequalities to the forefront of the analysis. Before elaborating on this possibility, it is first necessary to understand the analytical steps and the strengths and weaknesses of the integrated approach as it is typically implemented in practice. It is particularly important to understand the extent to which inequalities have or have not featured in integrated climate impact assessments.

Analytical steps and strengths of the integrated approach

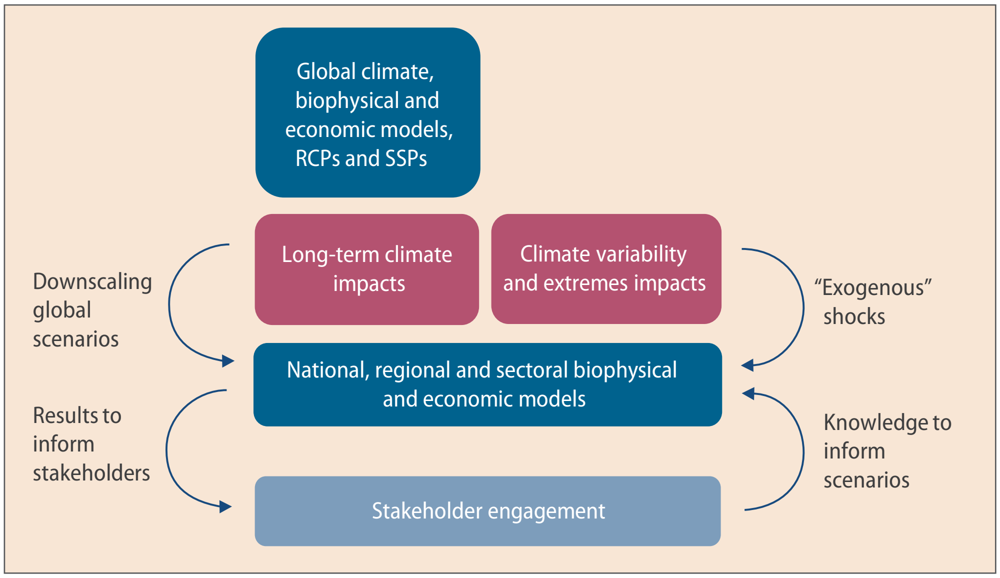
Climate impact assessments integrate different modelling tools to facilitate an understanding of the interlinkages across the various dimensions of development...

The integrated approach to climate impact assessments has a number of strengths: It relies on the expertise of natural and social scientists from across different disciplines; integrates modelling tools to facilitate an understanding of the multiple interlinkages across and within the environmental, economic and social dimensions of development; and aids in the estimation of climate-related impacts and deliberations on alternative policy responses. While this approach has been used mainly in assessing long-term climate impacts, it is also well suited (as shown below) to assessing short-term risks and it is thus useful to assess policy options for climate resilience.[3]

Figure III.1 provides a simplified representation of the cascade of analytical steps taken in this approach, and also depicts the extensions needed to incorporate climate variability and extreme weather events within the analysis, as well as the possible engagement of stakeholders in the assessment process.

Figure III.1

Simplified representation of the integrated approach to climate impact assessments



Source: UN/DESA.

Global climate models are generally used by natural scientists, to project climate changes, typically changes of temperature and precipitation patterns, over relatively large spatial and temporal scales.[4] These projections are influenced by different scenarios, for the world, of greenhouse gas emissions and concentration pathways, under different levels of mitigation, as given by so-called representative concentration pathways (RCPs). Projections derived from these climate models, under different degrees of confidence, feature prominently in the IPCC assessment reports and have been utilized as a tool for informing international climate negotiations.

Climate projections are subsequently downscaled through global biophysical models to simulate how they affect natural resource systems (land, energy and water). At this stage, an objective of the analysis may be to determine, without much socioeconomic detail, how changes in natural resource systems affect a particular area or sector. The IPCC Fifth Assessment Report, which is also the most recent, presents evidence emanating from biophysical models suggesting that climate change impacts are strongest and most comprehensive for natural systems (IPCC, 2014d, p. 4).

3 For a more detailed description of this approach, as typically taken in assessments of long-term climate change impacts, see Sánchez (2016).

4 These models are also known as global circulation models (GCMs).

More recently, there has been an incorporation of global economic models, generally by social scientists working with natural scientists in a multidisciplinary context, as a means of generating scenarios that translate changes in natural resource systems into changes in socioeconomic ones. At this step, shared socioeconomic pathways (SSPs), which were introduced in appendix I.1 of chapter I, are used to inform the scenarios through addition of details on population growth (disaggregated by age, sex and education), urbanization and economic development (proxied generally by growth of gross domestic product (GDP)), which are otherwise not specified in global economic models.

…thereby helping to generate a cascade of scenarios of potential climate impacts and vulnerabilities at different geographical levels

The cascade of global impact scenarios that are generated from these models is further downscaled if the purpose is to understand potential impacts and vulnerabilities at lower geographical levels. In this case, additional biophysical and economic models are used for countries, regions or sectors. Once all of the scenarios of impacts and vulnerabilities associated with climate projections have been assessed at global and lower geographical levels, additional scenarios can be run at different geographical scales to assess alternative policy responses for reducing adverse impacts.

The results of the scenarios generated are characterized by uncertainty and must therefore be interpreted with caution. Major sources of uncertainty include, among others, climate change projections under different levels of mitigation; climate variability; socioeconomic projections; model simplifications; and data constraints, particularly at the local level. With regard to simplifications of complex realities, the results from models critically depend on assumptions made in relation to people's behaviour. If modellers fail to incorporate plausible behaviours, model results may lead to the wrong conclusions.

Working with policymakers and relevant stakeholders is important when designing scenarios and interpreting results

Scientists and researchers who are developing integrated climate impact assessments have adopted certain practices in response to these limitations. In the field of climate, for example, uncertainty tends to be "deep",[5] which accounts for their recent practice of working closely with policymakers and relevant stakeholders to improve the estimation of parameters and the interpretation of results (see figure III.1, bottom right). In the context of such uncertainty, it is widely recognized that rather than offer predictions of the future, integrated climate impact assessments provide information on a plausible range of future outcomes that policymakers need to keep in mind.

Emphasis on mitigation and long-term climate change

Climate impact assessments have been focused more on mitigation and long-term climate change and less attention has been paid to the impact of climate hazards arising from climate variability and extreme weather events and on the policy options for adaptation and resilience. The focus on mitigation can be accounted for by the difficulty inherent in measuring adaptation. The concepts of adaptation and resilience have no common reference metrics comparable to the ones that exist for mitigation, namely, tons of greenhouse gases and radiative forcing values. Measuring adaptation would require a larger number of indicators relevant to each country and specific local context (Noble and others, 2014; see also chap. I).

5 Deep uncertainly arises when analysts do not know, or cannot agree on, how the climate system may change, how models represent possible changes or how to value the desirability of different outcomes (Jiménez Cisneros and others, 2014).

Nevertheless, the lack of common reference metrics for adaptation and resilience need not hinder analysis of those processes. By their very nature, adaptation and resilience are interwoven with broad development goals (i.e., reducing vulnerability to climate hazards requires livelihood improvements, food security, improved health systems, infrastructure development and better educational services). As meeting such goals requires a continuum of policies, planning and practices leading to transformative change and sustainable development (see chaps. I and II), any analysis that integrates those goals and policies will be multi-metric in nature. Integrated climate impact assessments are well suited to performing this function precisely because the multiplicity of models used makes it possible to integrate the different facets of development. The tools being used in integrated climate impact assessments also make it possible to analyse adaptation and resilience in the context not only of long-term climate change but also of climate hazards resulting from climate variability and extreme weather events.[6]

By virtue of their multi-metric nature, climate impact assessments help to integrate different dimensions of development, including adaptation and resilience

Insufficient analysis of the macroeconomic feasibility of policies

In integrated climate impact assessments, the impacts detected in climate and biophysical models are translated into socioeconomic impacts using economic models in order to produce a standard accounting of the costs and benefits of climate policy, typically the costs and benefits of a single project or intervention. There has been a tendency to use economic models that are aggregated and simple in terms of their data requirements and estimation techniques.[7] However, it is important to broaden the scope of the analysis to encompass not just a simple cost-benefit analysis of a single invention, but also the economy-wide repercussions and macroeconomic feasibility of policies, which requires the use of more comprehensive modelling approaches. This is particularly important given both the existing gaps in the financing of adaptation and the need to scale up investments in order to build climate resilience as discussed below and in greater depth in chapter V.

It is important to consider the economy-wide repercussions and macroeconomic feasibility of policies for climate resilience

Some of the most frequently used economic models (e.g., reduced-form econometric models) take prices as given, which means that they cannot trace changes in the allocation of resources resulting from price changes.[8] Other economic models (e.g., microeconomic structural and land-use models) do allow for changes in resource allocation but lack details

6 From a methodological point of view, there is ample evidence of the severity of impacts from climate extremes and variability on people and livelihoods (see chaps. I and II). This evidence provides an order of magnitude of potential shocks inflicted on natural resources and socioeconomic systems. Such information can be used in designing scenarios for integrated climate impact assessments. The sequence of analytical steps may begin with imposing an exogenous change (i.e., a "shock") on national, regional or sectoral models, without necessarily linking this with global models (see figure III.1, upper right). This makes it possible to estimate the sensitivity of outcomes to climate variability and extreme weather events as well as evaluate policy options.

7 However, it is not clear whether, on the contrary, the tendency to use the standard accounting of the costs and benefits of climate policy is actually due to a deliberate choice — that of using the simplest (albeit not the most useful) models available.

8 Reduced-form econometric models are based on the notion that adaptive responses to climate change can be represented by equations that relate climate variables directly to economic outcomes. These models are estimated econometrically using cross-sectional or panel data (pooled cross-sectional and time series) and are then simulated using projected future climate variables to determine the impacts of climate change on the dependent variable in the model.

on how prices are determined in different markets. In practice, however, prices in the different markets of the economy change over time, particularly in contexts characterized by changing climatic conditions: some agents may allocate resources differently in response to these changes.[9] Not allowing for resource allocation effects in economic modelling also makes it difficult to evaluate the macroeconomic and financial feasibility of policies. The allocation of funds to finance the implementation of policies aimed at climate resilience can, for example, crowd out other climate and non-climate investments and have unintended consequences for the economy. This would represent a case of policy incoherence or maladaptation (see chap. IV).

It is important that these considerations be kept in mind when the wider costs and benefits of climate policies are being assessed for the national economy as a whole. This presupposes the use of economy-wide models that are well suited to assessing the economic and financial feasibility of policies for climate resilience while taking into consideration the macroeconomic constraints.[10]

The tendency to exclude inequalities or address them inadequately

Few climate impact assessments address inequalities, with their methodologies being generally unsuited to tracing impacts on vulnerable groups

Even though inequalities exacerbate the vulnerability and exposure of disadvantaged groups to climate hazards, as noted in chapters I and II, they are often overlooked in integrated climate impact assessments. Their methodologies are generally not suited to tracing impacts on specific groups that are particularly vulnerable and only a few of those assessments incorporate equality considerations. As noted in chapter II, this explains both why the discussion on the social impact of climate change has been limited and why the interlinkages between climate change and inequality have yet to be fully explored.

Equality considerations in relevant studies are limited to the analysis of the "social cost of carbon" — the expected present-value damages arising from carbon dioxide (CO_2) emissions.[11] This type of analysis provides estimates for socially desirable mitigation policies; however, those policies are difficult to implement because the analysis assumes that people who benefit from them will be better off if they compensate those negatively impacted by the policy, which may not be the case in practice.

Another important assumption in these studies is that a dollar given to a poor person is the same as a dollar given to a rich one, so that it is then possible to add up monetized welfare losses across disparate incomes. "Equity weights" have been introduced to "relax"

9 For example, the prices of internationally traded food commodities interact with climate change (Porter and others, 2014). Changes in these prices tend to have a greater effect, in particular, on the welfare of households that use a large income share to purchase staple crops (Olsson and others, 2014). As a consequence, these households may adapt by shifting their consumption habits, which would have implications for their vulnerability and well-being.

10 Economy-wide models are also known as computable general equilibrium (CGE) models. Partial equilibrium (PE) models and CGE models belong to the family of market equilibrium models. Both types of models help simulate the effects of "shocks" or changes in productivity, policy or other factors such as climate on various economic outcomes, including market equilibrium prices, production, productivity, consumption, trade and land use. CGE models are particularly suited to tracing effects that work through the different markets of the economy (e.g., factors, commodities and foreign exchange), under given macroeconomic constraints.

11 Present values in these assessments are estimated based on a discount rate. The lower the discount rate, the higher the estimates of climate-related costs. There is considerable disagreement among economists regarding the rate (or rates) at which future costs and benefits should be discounted.

this unrealistic assumption, which has significantly changed the results of calculating the social cost of an incremental emission (Anthoff, Hepburn and Tol, 2009). This has represented an important step towards accepting the suggestion that equality should be a prime concern in climate policy. However, owing to data restrictions, equity weights tend to be constructed based on average per capita income of regions rather than of individuals.[12] Furthermore, approaches to equity weighing may not be appropriate from the point of view of a national decision maker because domestic impacts of global emissions are not valued at domestic prices (Anthoff and Tol, 2010).

Not only is mitigation the focus of the studies cited above, but their approaches to equality (i.e., entailing the social cost of carbon and equity weights) are inadequate for the purpose of tracing impacts on the specific groups that are particularly vulnerable to climate hazards. Thus, there is a serious gap in addressing inequalities in the literature on integrated climate impact assessments, even in the few existing assessments that focus on adaptation.

Only 2 of the 13 economic assessments of adaptation options reviewed in the IPCC Fifth Assessment Report addressed issues that matter for inequality

The IPCC Fifth Assessment Report suggests that few assessments examine how inequalities shape differential vulnerabilities to climate change (see Olsson and others, 2014). A review of 13 economic assessments of adaptation options in the Fifth Assessment Report, spanning the period from 2006 to 2013, corroborates this observation (table III.1). Only two of the studies addressed health issues that matter for inequality, and in both, inequality was not a central theme. One analysis, whose focus was diarrhoeal diseases, placed emphasis on the major burdens among the poor and evaluated different policy options for addressing this vulnerability. The other study evaluated adaptation options that reduce undernourishment, a potentially serious public-health problem which can deprive generations of opportunities. While some of the studies provided an analysis of the effects of climate change on food security and the livelihoods of the rural poor, or considered different types of farms, they did so without making any explicit reference to inequalities; and another study considered inequalities only contextually. It is also noteworthy that few of the studies addressed the macroeconomic repercussions of adaptation policies.

Analytical dimensions of inequalities in climate impact assessments

Inequalities can be featured more prominently in integrated climate impact assessments through the combining of modelling tools

It is possible to use different combinations of modelling tools to explore the four analytical dimensions of inequalities as part of an integrated climate impact assessment that addresses adaptation, resilience, climate variability and extreme weather events. Existing modelling frameworks can be integrated to enable an exploration of four analytical dimensions of inequalities. The role of stakeholders in providing information and expertise is critical both to improving modelling results in general and to providing insights regarding vulnerabilities to climate hazards.

Table III.2 summarizes the four analytical dimensions of inequalities, and the different modelling frameworks that can be used to address each one of them. The present section discusses each dimension in detail with regard to its relevance for integrated climate impact assessments. It also presents the findings derived from existing analyses that help to explain the strengths and weaknesses of those modelling frameworks and show the kind of policy options that may function as enablers of climate resilience in a specific country context.

12 It has recently been shown that a more fine-grained representation of economic inequalities within regions is an important consideration for the estimation of the social cost of carbon (Dennig and others, 2015).

Table III.1

Consideration of inequalities in economic evaluations of adaptation options

Sector	Study, scope and methodology	Consideration of inequalities[a]
Agriculture, forestry and livestock	Seo and Mendelsohn (2008). Seo and others (2009). Economic choices of livestock owners to maintain production in the face of climate change in African countries. Econometric analysis	Different farm types, without analysis of inequalities
	Butt, McCarl and Kergna (2006). Economic implications of potential adaptation possibilities in cropping systems in Mali. Simulation analysis	The analysis shows that adaptation reduces climate change-related economic losses and undernourishment
	Sutton, Srivastava and Neumann (2013). Climate effects and adaptation for the crop sector in four Eastern European and Central Asian countries. Simulation with cost-benefit analysis. Considers non-market and socially contingent effects through the stakeholder consultation process	The analysis addresses the effects of climate change on food security and livelihoods of the rural poor. No explicit reference to inequalities is made
Sea-level rise and coastal systems	Nicholls and Tol (2006). Coastal regions at a global scale. Simulated adaptation options for coastal regions at the global scale (i.e., construction of sea walls and levees, beach nourishment and migration)	No
	Neumann (2009). Risks of sea-level rise for a portion of the coastal United States of America. Simulated adaptation options, including sea walls, bulkheads, elevation of structures, beach nourishment and strategic retreat	No
	Purvis, Bates and Hayes (2008). Risks of coastal flooding in Somerset, England. Simulation using a probabilistic representation to characterize uncertainty in future sea-level rise and other factors that could affect coastal land-use planning and development investment decisions	No
Water	Ward and others (2010). Water investments at the municipal level across the world, scaling down to national and local scales. Analysis through an optimization algorithm. Costs with and without climate change of reaching a water-supply target in 2050 are assessed	No
Urban flooding	Ranger and others (2011). Direct and indirect impacts of flooding in Mumbai, India. Global climate change downscaled to city level to investigate the consequences of floods and simulate improved housing quality and drainage and access to insurance	No
Energy	Pereira de Lucena and others (2010). Energy production in Brazil under future climate conditions, focusing on hydropower. Simulation of multiple adaptation options, including substitution of energy sources. Uses an optimization model of energy production	No
Health	Ebi (2008). Climate scenarios to address costs and policy responses. Global adaptation costs of treatment of diarrhoeal diseases, malnutrition, and malaria, downscaled for analysis in Indonesia and South Africa	Inequality is not the central theme but the analysis of diarrhoeal diseases places emphasis on the major burdens among the poor. Policy options include breastfeeding promotion, rotavirus immunization, measles immunization and improvement of water supply and sanitation
Macroeconomic analysis	De Bruin, Dellink and Tol (2009). Adaptation strategies compared with mitigation strategies for the world. Adaptation options include investments in infrastructure and market responses. Use of an integrated assessment model with refined adaptation functions to analyse policy options	No
	Margulis, Dubeux and Marcovitch (2011). Impacts of climate change trends on Brazil's economy. Socioeconomic trends approximate adaptation. Global trends downscaled to a general equilibrium model to quantify impacts on agricultural, livestock and energy sectors	Reference to inequalities is essentially contextual

Source: UN/DESA, adapted from Chambwera and others (2014), table 17-4. Last column has been added.

a There is deemed to be a consideration of inequalities if the study addresses inequalities in respect of access to basic public services, climate-related effects on human development, or income inequality.

Table III.2
Sources of inequality in modelling frameworks

Sources of inequality	Modelling approach	Strengths of modelling approach	Weaknesses of modelling approach
Livelihoods relying on climate-sensitive natural resources	Biophysical modelling	Detects impacts on livelihoods that depend on climate-sensitive natural resources	Relies on assumptions about behaviour without incorporating behavioural change, which is critical for adaptation
		Detects how changes in one natural resource may impact other natural resources	Changes in natural resources are not fully translated into socioeconomic changes
		Suggests how natural resources can be allocated more efficiently for adaptation	Does not specify effects on the livelihoods of disadvantaged groups in particular
			Data-intensive
Ownership and employment of production factors	Economy-wide modelling	Allows for estimation of indirect impacts of climate hazards and policies, detecting losers and winners; factor income distribution; resource allocation and thus some aspects of adaptation; and policy feasibility	Relies on assumptions regarding behaviour without incorporating behavioural change, which is critical for adaptation
		Can include human development indicators as a function of socio-economic determinants, including public investments in social sectors and infrastructure	Because of the aggregation of representative household groups, estimates of changes in income distribution may be biased
Human capital and access to public services and resources			Limited with respect to addressing other forms of primary inequality beyond income
			Data-intensive
Socioeconomic characteristics at the household level	Microsimulation modelling (with household surveys, prefereably linked to economy-wide model)	Adds value in identifying vulnerability associated with socioeconomic characteristics (e.g., gender, age, race, religion and ethnicity) whose intersection defines inequalities	Relies on assumptions about behaviour without incorporating behavioural change, which is critical for adaptation
		Points to possible policy options for reducing vulnerability	Limited analysis of financial feasibility of policies
		Less data-intensive when at least one household survey is available	Depends on the quality and coverage of household surveys

Source: UN/DESA.

Livelihoods and climate-sensitive natural resources

Climate projections can be translated into changes in natural resource systems that support the livelihoods of vulnerable populations

Livelihoods that depend on climate-sensitive natural resources, such as land, water and energy, are exposed to climate hazards (see chap. II). Amid poverty and structural inequalities, large groups of people and communities whose members secure a living in climate-sensitive environments also face high vulnerability to climate hazards. Understanding how such vulnerability translates into actual impacts on the economy and inequality first requires an analysis of the impacts of climate hazards on climate-sensitive natural resources.

This type of analysis begins with biophysical models (models for land, water and energy systems) which help translate climate projections (derived from climate models) into changes in natural resource systems. The analysis can be designed to assess adaptation options, too. For example, Bhave and others (2016) have downscaled regional scenarios of future climatic change through a water systems model in order to estimate impacts on water availability in India's Kangsabati river basin. In assessing policy options, they found that increasing forest cover is more suitable for addressing adaptation requirements than constructing check dams. Different studies in Cervigni and others, eds. (2015) use an energy systems model to channel the impacts of a wide range of future climate scenarios on hydropower and irrigation expansion plans in Africa's main river basins (Congo, Niger, Nile, Orange, Senegal, Volta and Zambezi). Those studies suggest that hydropower infrastructure needs to be developed irrespective of the scenario for water availability.[13]

Integration of climate, land, energy and water models facilitates an understanding of how natural resources can be allocated more efficiently for adaptation

Each natural resource systems model (whether for land, water or energy) is useful in its own right. However, a more holistic approach, through which those systems models are integrated, is better suited to facilitating an understanding of how changes in one resource resulting from a climate hazard may impact other resources, as well as how natural resources can be allocated more efficiently to meet the demands for crops, water and energy services, or to achieve a broader form of adaptation. A number of favourable studies present the advantages of using the Water-Energy-Food Security Nexus and Climate, Land, Energy and Water Systems (CLEWS) frameworks, which integrate different natural resource systems models.[14]

The International Renewable Energy Agency (IRENA) (2015) has reported the noteworthy findings derived from a number of exploratory case studies on the Water-Energy-Food Security Nexus. One study showed that half of China's proposed coal-fired power plants, which require significant water for cooling, are located in areas already affected by water stress, leading to potential conflicts between power plant operators and other water users. Another study demonstrated that, in India, where nearly 20 per cent of electricity-generation capacity is used for agricultural water pumping, lower-than-usual rainfall accompanied by decreasing water tables is putting tremendous stress on the electricity system during peak seasons. These two examples underline the functionality of the Water-Energy-Food Security Nexus approach in yielding important policy insights centred around the fact that water, which is constrained by climate change, faces competing allocations between energy generation and other uses such as in farming. The scarcity of water can hamper farmers in their pursuit of a livelihood and it may not be easy for them to find alternative means of coping with these changes.

Another example is provided by the island of Mauritius, where important policy concerns have been addressed using the CLEWS framework (Howells and others, 2013). Facing the recent loss of the sugar industry's export competitiveness, the Government has considered two policy objectives: developing bioethanol production to reduce greenhouse gas emissions and cutting energy imports. These objectives may have important implications for livelihoods because achieving them entails diverting sugarcane production away from export markets towards the domestic processing of bioethanol on an island where sugarcane plantations cover 80-90 per cent of cultivated land. The CLEWS analysis showed that

13 The studies find that under the driest climate scenarios, there could be significant losses of hydropower revenues and increases in consumer expenditure for energy. Alternatively, under the wettest climate scenarios, substantial revenues could be forgone if the larger volume of precipitation was not utilized to expand hydropower production.

14 Using the CLEWS framework for Mauritius, Welsch and others (2014) have demonstrated the advantages of integrating natural resource systems instead of using an energy systems model alone to analyse energy pathways, given the importance of decreasing rainfall and future land-use changes.

the two policy objectives can be achieved, but not without important trade-offs. In recent years, lower rainfall has led to water shortages on the island which, under scenarios of climate change, implies that the water needed for sugarcane production would be supplied through irrigation so as to maintain bioethanol production. This would ultimately lead to a gradual drawdown of storage levels in reservoirs; and if the demand for more energy needed to desalinate water for irrigation is met with coal-fired power generation, as planned, then the greenhouse gas-related benefits of the bioethanol policy will be eroded by increased emissions from the power sector. Higher coal imports would also have a negative impact on energy security. Hence, the benefits of the policy are vulnerable to the impacts of climate change.

As a result, the island faces two possibilities. Either sugarcane producers will eventually have to scale back production (which would jeopardize the livelihood of populations that rely on that production) or they will have to resort to expensive water desalination (which would have detrimental environmental impacts). The CLEWS analysis has prompted the Government of Mauritius to start thinking about how to adapt to these challenges.[15]

The holistic approach to natural resource systems analysis offers a first point of entry into the area of analysing inequalities in integrated climate impact assessments...

This holistic approach to natural resource systems analysis offers a first point of entry into the area of analysing inequalities in integrated climate impact assessments. It allows for an understanding, with some precision, of how climate-sensitive natural resources are affected by climate hazards, with and without the presence of adaptation policies, and provides information on how, as a result, the livelihoods that depend on those resources are affected. However, identification of the specific distributional impacts of climate hazards and the policy options available to offset them would require additional socioeconomic analysis.

...but socioeconomic modelling frameworks are still necessary to assess changes in climate-sensitive natural resources throughout the economy

In the CLEWS analysis for Mauritius, for example, under the scenario where sugar cane producers scaled back production owing to climate change, unemployment, welfare and perhaps income distribution would likely be affected. The population that owns factors of production employed in the bioethanol industry, whether labour, capital or land, could be adversely affected in the process. However, these impacts are not quantifiable by applying the CLEWS methodology (nor by applying the Water-Energy-Food Security Nexus approach for that matter). They would require the complementary use of socioeconomic modelling tools to bridge this methodological gap. Economy-wide models are particularly well suited to initiating understanding on how changes in climate-sensitive natural resources, as identified through natural resource systems models, affect the economy. In addition, household survey analysis would be particularly useful in capturing the distributional impacts of shocks, including those affecting livelihoods in climate-sensitive environments.

Ownership of production factors and income distribution

Channelling the physical impacts of climate hazards on natural resources throughout the economy provides useful information on the income gains and losses of people with

15 In his address delivered at the 3rd plenary meeting of the United Nations Conference on Sustainable Development, held in Rio de Janeiro, Brazil, from 20 to 22 June 2012, the Minister of Environment and Sustainable Development of Mauritius, Devan and Virahsawmy, pointed out that the government programme for 2012-2015 already provided for the appointment of a high-level CLEWS panel to ensure an integrated approach to all climate, land, energy and water strategies (see http://webtv.un.org/search/mauritius-general-debate-3rd-plenary-meeting-rio20/1700992573001?term=Devanand%20Virahsawmy).

different factor endowments, these being labour, land and capital. Climate hazards have disproportionate impacts on the assets of vulnerable groups owing to the disruption of economic activity and the resulting unemployment of production factors. For disadvantaged groups, a small but adverse change in the employment of the production factors upon which their livelihoods rely (generally labour and land) will likely exacerbate their vulnerability and exposure to climate hazards. However, the impact of climate hazards propagates throughout the entire economy: poverty and distributional impacts will be the result of the multiple direct and indirect effects of the initial shock. This multiplicity of transmission mechanisms emerging from the direct impact of climate hazards justifies the use of economy-wide models in integrated climate impact assessments.

Economy-wide modelling analysis can transmit the impacts of climate hazards through the employment of production factors...

Several examples help illustrate the functionality of the economy-wide modelling framework. Sánchez (2016) shows that, within the context of the Plurinational State of Bolivia, a reduction in labour productivity as a result of the impact of rising temperature on workers' health, or a destruction of public infrastructure after an extreme weather event, can result in lower labour wages, both in absolute terms and relative to capital. Household members whose livelihoods rely on labour income, and who generally belong to vulnerable groups, lose out in the process. While additional scenarios show that public investment options would help in coping with the simulated climate shocks, further analysis indicates that, under existing fiscal constraints, financial options for these investments may jeopardize macroeconomic stability and economic growth. The fact that some policy options may thus have unintended consequences points to the importance of analysing the macroeconomic feasibility of policies for climate resilience.

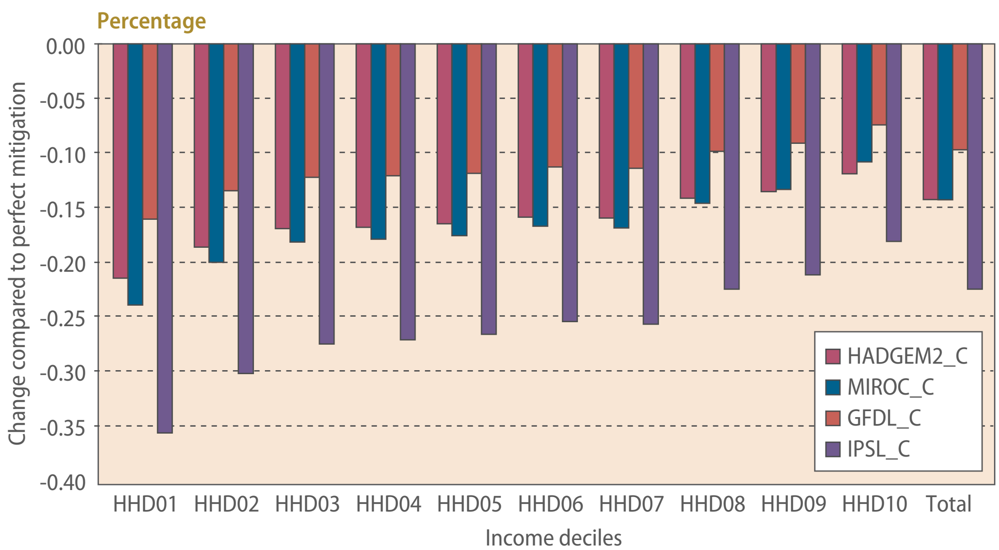
...enabling the identification of "winners" and "losers" with and without adaptation options

This type of economy-wide analysis also permits identification of situations where there may be winners from changing climate conditions, which could result in a reduction of inequality and poverty. The same analysis for the Plurinational State of Bolivia (Sánchez, 2016) shows that, in an alternative scenario where the world price of food increased, presumably as a result of climate change, farmers and food producers would win relative to producers in other sectors. Unskilled non-salaried workers would benefit most from the food price shock because of the large presence in food production of small-scale farmers and self-employed workers, who constitute an important share of the total population. In the face of a situation such as this, public policies would have an important role to play in strengthening the capacity of small-scale food producers to benefit from the price hike by facilitating market access and the eventual increase in production. In addition, policy options would have to be considered for reducing the burden imposed by the price shock on vulnerable consumers.

Another interesting example in this regard is provided by a recent integrated climate impact assessment, undertaken under the auspices of the International Food Policy Research Institute (IFPRI) (Andersen and others, 2016). The analysis estimates the impact of crop-yield losses in the order of 10-30 per cent over the next half century owing to the impact of climate change. The study finds that such a significant shock would not necessarily translate into proportional income losses for farmers or the population in general if farmers were to find ways to adapt autonomously. It was found that this would indeed be the case within the contexts of Brazil and Mexico if farmers in these countries had the capacity to modify planting dates in order to maximize crop yields, shift towards climate-resilient crops or migrate to different agro-climatic zones. As a result, the final effects of climate change would tend to be smaller than that of the initial crop-yield shock and the net effects on income of different household groups would be modest in either direction. In Mexico, 80 different household types were analysed (differentiated by gender of household head, agroecological zone and income decile), with impacts being very similar for them all, i.e., there were tiny losses in welfare between 0.1 and 0.3 per cent. Interestingly, this small effect on income across income deciles is robust to the choice of climate model (figure III.2).

Figure III.2

Combined impacts of global price and local yield changes on net present value of household welfare in Mexico, by income decile, under a climate change scenario relative to a perfect mitigation scenario



Source: Andersen and others (2016), figure 28.
Note: HHD01 to HHD10 = first to tenth income decile, _C = combined scenario of global price changes and local yield changes, resulting from climate changes simulated through four global climate models (GFDL, HADGEM2, IPSL and MIROC). These scenarios are passed on to an economy-wide model for Mexico so that income effects can be analysed.

While the IFPRI study was not intended to analyse adaptation policies per se, the results of such a study are useful in informing policymaking aimed at climate resilience. It suggests that the capacity of farmers to adapt autonomously to climate change is critical in the long run. Policy options with a focus on inequality and poverty should thus accelerate this adaptation process through, for example, public investments in infrastructure that boost productivity and incentives for adopting climate-resilient technologies. Further analysis of planned adaptation strategies, in farming, for example, might be explored by integrating more disaggregated models, such as crop and livestock models as explained further below.

Assessments need to be taken one step further — to the microlevel — to facilitate an understanding of impacts across households

Albeit a necessary step, the analysis of income generated (mostly through employment of production factors) and its distribution across different household groups is insufficient. It is useful because households located at the lowest deciles of a distribution are those that tend to exercise relatively less ownership over production factors and assets in general. They are generally vulnerable and understanding how their income changes in the face of climate hazards is important. Changes in the income of these households can be compared with changes in the income of households located in higher income brackets. However, this approach to distributive analysis is still highly aggregative, even if households groups are classified according to income decile, and misses out on the details of income distribution within household groups, which can ultimately affect the well-being of vulnerable households.[16] Nor is economy-wide analysis alone well suited to addressing other forms of inequality, including those that are determined by certain configurations of socioeconomic characteristics such as gender, age, race, religion and ethnicity. Analysis at a level that is more micro in nature helps surmount these methodological limitations, but before describing that form of analysis, it is important to understand another useful feature of the economy-wide modelling approach.

Human capital, public services and resources

Exploring human development policy options for the resilience of disadvantaged groups is a necessary facet of climate impact assessments

In coping with climate hazards, the poor and disadvantaged groups often face the difficult choice between protecting their human capital (health and education) and preserving their physical capital or even their consumption levels (see chap. II). Those groups face such choices because they are under an income constraint and may also have insufficient access to basic public services and resources. These are factors that act as important determinants of vulnerability to climate hazards. Exploring human development policy options for the climate resilience of these groups is a necessary facet of climate impact assessments.

The long-term effects of climate change on human development have been estimated mainly through using (reduced-form) econometric models, which found that climate change, for example, would reduce life expectancy, in Peru (Andersen, Suxo and Verner, 2009); depress people's incomes, in Chile (Andersen and Verner, 2010); and encourage within-country migration, in the Plurinational State of Bolivia (Andersen, Lund and Verner, 2010). Some economists argue that such long-term econometric estimations constitute a means of capturing the various economic adjustments or adaptations that occur in response to climate change and can be interpreted as reflecting a type of "analog" approach to climate impact assessment (Antle and Valdivia, 2016). Econometric models, however, do not provide information on the feasibility of human development policy options within a consistent macroeconomic framework.

Human development options can be addressed within the contours of economy-wide modelling. In this case, the models have the potential to specify human development indicators as a function of socioeconomic determinants such as household income; private and public spending on education, health, water and sanitation; and public infrastructure.[17] These indicators enhance the multi-metric character of integrated climate impact assessments and bring inequality in access to basic services to the forefront of the analysis. However, while economy-wide analyses with these characteristics do exist, they have not featured prominently in climate impact assessments.

For example, an economy-wide analysis for Bolivia (Plurinational State of), Costa Rica and Uganda presenting such characteristics has explored the scope for scaling up public investments in human development by raising public revenue through an implicit carbon tax (Sánchez and Zepeda, 2016). Scenarios show that the direct impact of imposing a carbon tax will be to reduce economic growth, but that this unintended consequence could

16 Even an approach that introduces a function to represent the income distribution within each household group is limited by the assumption that the variance of the distribution within each group is fixed.

17 It is important to underline that economy-wide models may in this case still necessitate an econometric approach, through which the elasticities of human development indicators with respect to socioeconomic determinants are estimated. Using econometrically estimated parameters is an accepted practice, particularly in an assessment approach that relies on the integration of modelling tools.

be offset by increasing investments in public infrastructure. The overall economy-wide impact of a carbon tax to finance public investments will be increasing economic growth, improved primary completion rates and reduced child mortality rates. The improvement in social indicators is the result of more equal access to basic public services in education and health. The construction of this type of scenario can inform decision-making processes through exploration of options for building development policy coherence by pursuing the simultaneous objectives of reducing greenhouse gas emissions and building climate resilience through reduction of inequalities in the access to basic services.

Additional examples in this regard are found in economy-wide modelling analyses for 27 countries from different developing regions which demonstrated that scaling up public spending in primary education, health, and water and sanitation would have allowed for faster progress towards achieving the Millennium Development Goals (Sánchez and others, 2010; Sánchez and Vos, 2013).[18] However, these analyses also illustrate the importance of giving full consideration to the financial sources for investment, as fiscal sustainability and economic growth were found to be in peril when particular financing options were utilized. Again, this type of analysis is useful in assessing trade-offs associated with building resilience through improved access to basic public services without jeopardizing economic growth and macroeconomic stability.

Socioeconomic characteristics at the household level

Alone or combined, gender, race, ethnicity, religion and other socioeconomic attributes of people, can, depending on context, generate inequalities with important roles in defining exposure and vulnerability to climate hazards (see chap. II). Analysis conducted at the micro level making better use of household surveys adds value in terms of identifying households whose exposure and vulnerability are determined by specific socioeconomic characteristics.

Analysis using household surveys helps identify households whose exposure and vulnerability are determined by specific socioeconomic characteristics...

Such an analysis need not be complex: it can rely on a single household survey and a simple definition of vulnerability. Andersen and Cardona (2013), for example, used the household survey for 2011 of the Plurinational State of Bolivia to construct indicators of vulnerability (and resilience) on the basis of level and diversification of income. Using these indicators to identify the types of households most likely to be vulnerable to shocks according to different socioeconomic attributes (see appendix III.1), they found that the households that were particularly at risk of being vulnerable were young households with high dependency burdens, large households, urban households (given that, in the Plurinational State of Bolivia, it is income in rural areas that is more diversified) and households in indigenous communities. Importantly, how socioeconomic characteristics shape vulnerabilities is context-specific. Using a panel of data from the Ethiopian Rural Household Survey (1994-2004), Dercon, Hoddinott and Woldehanna (2005) found that female-headed households were particularly vulnerable to drought-induced shocks.

...and provides useful information for policy analysis through the simple microsimulation of counterfactual scenarios

This kind of analysis utilizing household surveys provides useful information for policy analysis through the simple microsimulation of counterfactual scenarios. For example, a microsimulation of an evenly distributed cash transfer in the Plurinational State of Bolivia in the amount of 80 bolivianos (Bs) per person per month (equivalent to US$ 0.38 per day), using the same 2011 household survey mentioned above, showed that, although

18 For a combined analysis of the public spending and economic growth results for all 27 developing countries, see United Nations (2016, chap. II).

the transfer was not sufficient to ensure survival, it did reduce vulnerability and increased resilience (table III.3). When the monthly transfer was targeted specifically at people living in poverty, the transfer increased substantially (to Bs 175) without, however, increasing the total costs of the programme. Although the exercise considered neither the feasibility of financing such a programme nor the complexities of targeting, it did point to the potential effectiveness of that programme in reducing vulnerability and increasing resilience.

Table III.3

Effects of policies on per capita income, vulnerability and resilience under microsimulation scenarios in the Plurinational State of Bolivia

Baseline scenario and alternative scenarios	Income per capita (Bs per month per person)	Share of households that are highly vulnerable (percentage)	Share of households that are highly resilient (percentage)
Baseline situation, Plurinational State of Bolivia, 2011	1 360	14.9	33.5
Citizen salary of Bs 80 per month per person	1 440	6.3	45.3
Cash transfer of Bs 175 per month to all poor persons	1 428	3.7	44.1
Prevention of all teenage pregnancies	1 464	11.3	38.7

Source: Microsimulations based on the vulnerability methodology of Andersen and Cardona (2013).
Note: Vulnerable households have low levels of income and of income diversification. Resilient households do not live in poverty and their income is diversified. The thresholds that determine when a household is "highly vulnerable" or "highly resilient" are defined in appendix III.1.

More complex policy microsimulation scenarios can be evaluated. For example, consider a scenario where, rather than bear children before they are 20 years of age, young Bolivian women work for a minimum wage (Bs 815 per month). It is assumed implicitly that instead of raising children in their teens, those women were able to receive more of an education and have more time to work. The results of this scenario show an increase in per capita income and a reduction in the share of vulnerable households. Although this policy does not yield results as impressive as those achieved under the simulated programme of cash transfers to all people living in poverty, as described above, it requires a much lower investment of public resources (less than 1 per cent of the costs of the cash transfer programme). In contrast, the simulated universal cash transfer requires public spending in the order of 5 per cent of gross domestic product (GDP).

Supplementing household survey analysis with economy-wide analysis is necessary when putting the economic feasibility of social policies under scrutiny

Complementing such microsimulation analysis with the use of an economy-wide model helps determine if such social protection policies would be economically feasible in practice. Typically, the analysis begins by developing an understanding of the macroeconomic repercussions of the policy and its financial and macroeconomic feasibility through the use of an economy-wide model. Subsequently, key information on employment and income changes emanating from this analysis is passed on to the household survey to determine distributive impacts through microsimulation (Vos and Sánchez, 2010). The strength of this approach lies in the fact that effects are quantified for the "full" income distribution (i.e., at a disaggregated level) and not across different types of household groups, as would be the case if an economy-wide model was used alone. Combining these two methodologies is highly useful in integrated climate impact assessments.

It was not until recently that methods for including income distribution in economy-wide models for long-term climate change research began to be reviewed (see van Ruijven, O'Neill and Chateau, 2015). On the other hand, some already existing studies have provided interesting illustrations of the usefulness of this approach. Cicowiez and Sánchez (2011), for example, applied the approach to assess the impacts and feasibility of cash transfer programmes targeting households living in poverty in Latin American countries. They found that while these transfers led unambiguously to a reduction in income inequality, financing and sustaining them under existing fiscal constraints depended largely on sustained economic growth.

Vulnerability through the lens of stakeholders

Uncertainty and the intrinsic limitations of modelling require stakeholders' engagement in building scenarios and discussing results

The modelling frameworks described above can generate scenarios for climate resilience that are useful in informing policymaking, particularly when they are integrated. As noted in the introduction to the present chapter, those scenarios are characterized by uncertainty and by the intrinsic limitations of modelling, which is what has prompted analysts and researchers to work with stakeholders. Feedback from stakeholders on the ground is proving useful in the design and reassessment of scenarios, and the incorporation of the detailed information provided has helped reduce uncertainties.[19] This feedback is in fact critical because stakeholders provide information and share knowledge regarding factors that exacerbate their exposure and vulnerability to climate hazards, on one hand, and adaptation options that are relevant to increasing their resilience, on the other.

The benefits of engaging stakeholders in scenario design and policy dialogue are well documented. In its consideration of adaptation to future flood risk in the Thames Estuary, the United Kingdom Environment Agency applied four scenarios over three time periods to flood management. Based on the outcome of a wide consultation process, it was determined that improving the current infrastructure would continue to be the preferred strategy until 2070, when construction of an outer barrage might become justifiable, especially as economic and climate change conditions changed over time (O'Brien and others, 2012). To facilitate the analysis centred on water availability and climate change in India's Kangsabati river basin, as mentioned above, the authors organized multilevel stakeholder workshops to identify and prioritize adaptation options which were subsequently evaluated using a water systems model (Bhave and others, 2016). Another study entailed an examination of climate impacts and adaptation within the context of the crop sector in four countries in the region of Eastern Europe and Central Asia. The scenarios considered non-market and socially contingent effects, including information derived from a stakeholder consultation process (Sutton, Srivastava and Neumann, 2013).

The Agricultural Model Intercomparison and Improvement Project (AgMIP) is perhaps one of the best examples of an initiative relying on stakeholders for scenario-building. The Inter-comparison and Improvement Project developed the regional integrated assessment (RIA) framework and the concept of representative agricultural pathways (RAPs). While the RIA framework links global and regional scenarios essentially along the

19 From a modelling point of view, this feedback helps to improve model "parametrization" and calibration (Jiménez Cisneros and others, 2014), among other benefits.

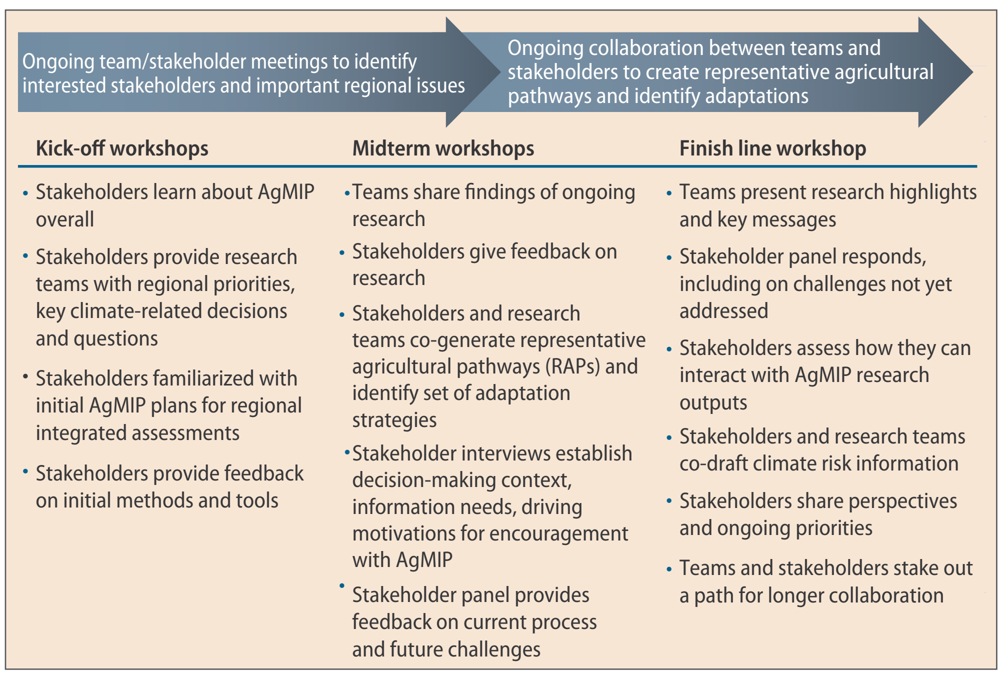
lines of the integrated approach discussed above, a number of features of this framework stand out.[20] Using farm survey data for regions, the framework enables the study of heterogeneous populations of farm households whose livelihoods depend on agricultural systems. Representative agricultural pathways are one of the outstanding features: they add further details about the future socioeconomic (non-climate) conditions to which farm households may be exposed and also help project a level of detail on inputs that generally does not exist in models.

Engaging decision makers, experts and farmers has proved critical in modelling climate change impacts and adaptation options...

In developing their regional studies with the AgMIP-RIA framework, research teams engage in ongoing interactions and activities with stakeholders over the life of the project (figure III.3). Specific milestones are reached by or during the AgMIP regional workshops. Two groups of stakeholders participate: higher-level decision makers and experts, and communities of farmers. The interactions with these stakeholders are particularly important for scenario design; they follow several cycles, with each cycle encompassing the several steps needed to develop the representative agricultural pathways (starting in the midterm workshops).

The AgMIP-RIA framework is being applied by regional teams (researchers and stakeholders) in sub-Saharan Africa and South Asia to assess climate change impacts, vulnerability and the potential for adaptation strategies. For these assessments, the regional

Figure III.3
The AgMIP national and regional engagement process



Source: Antle and Valdivia (2016).

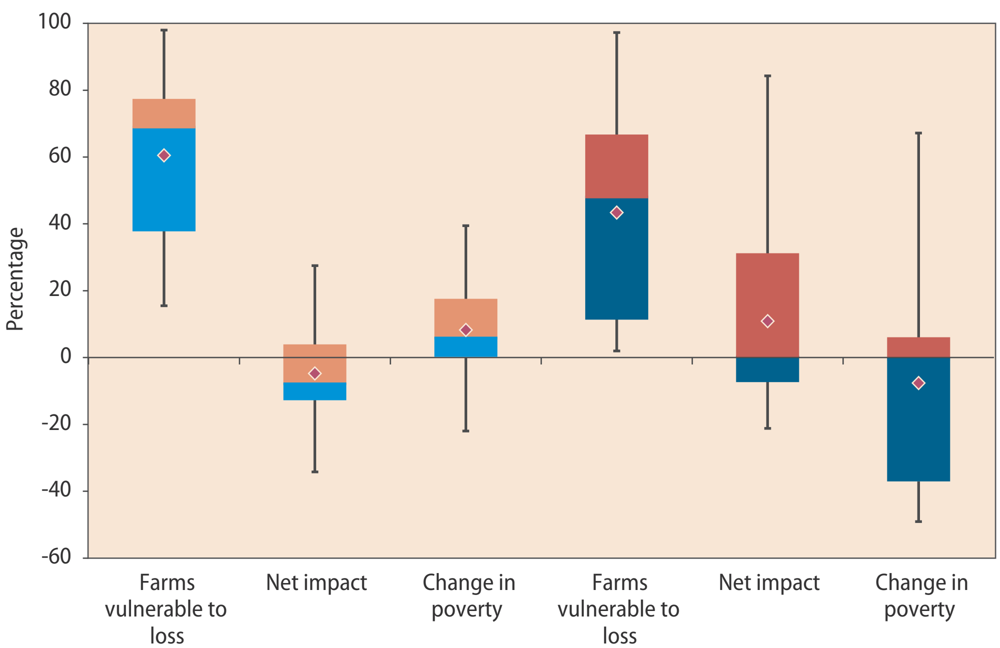
20 Crop and livestock models are used to translate the biophysical consequences of climate change into economic impacts at the regional level. These impacts are further understood through simulations using the microeconomic structural model known as the Trade-off Analysis model for Multidimensional impact assessment (TOA-MD). For a stylized representation of the linkages between models and data for climate impact, adaptation, mitigation and vulnerability assessment in the AgMIP-RIA framework, see Antle and Valdivia (2016), figure 5.

teams devise representative agricultural pathways for each of the regions providing region-specific information that supports the construction of several key indicators describing future biophysical and socioeconomic conditions (Valdivia and others, 2015). The knowledge shared by stakeholders has been critical for capturing the large degree of heterogeneity in the key indicators and trends among the regions' farm population.[21] This is a key factor in modelling the way in which systems are impacted by climate change and how they can adapt to it.

Because it is heterogeneous populations that are under study, unsurprisingly, the AgMIP regional studies demonstrate that there is a wide range of vulnerability to climate change under current socioeconomic conditions. About 60 per cent of farmers, across study sites, are currently vulnerable to net income losses due to climate change (figure III.4). Results also show that under a scenario characterized by more favourable future socioeconomic conditions (as defined by the regional representative agricultural pathways), 40 per cent of farmers (not 60 per cent, as under current conditions) would be vulnerable to climate change, which means both an avoidance of potential income losses and the experiencing of less poverty. This demonstrates the importance of accelerated socioeconomic developments in reducing vulnerability to climate change and poverty.

Figure III.4

Current and future climate change impacts on farms located in agricultural regions of Africa and South Asia, 2005 and 2050



Source: Antle and Valdivia (2016), based on data in Rosenzweig and Hillel, eds. (2015).
Note: Impacts are estimated from a climate change scenario using the integrated climate impact assessment approach described above (adding a crop model). This scenario was generated under current conditions and more favourable socio-economic conditions in the future, as perceived by farmers (and captured by representative agricultural pathways). The results for current and future conditions are presented for 2005 and 2050, respectively. Bars include the results for all farms in the areas of study; within the bars, boxes represent quartiles and diamonds represent averages. Boxes in light blue (left side) and dark blue (right side) indicate current and future socio-economic conditions, respectively. Net impact represents the net effect on farm returns.

21 For example, a trend towards increased soil degradation has been identified as a major issue by researchers working with stakeholders. However, the magnitude of soil degradation is not as large in regions where there is more government investment in agriculture, promotion of better soil conservation activities, and increased fertilizer use.

...and has helped reduce uncertainty in scenario results and produce a more realistic assessment of options

A comparison of AgMIP studies analysing impacts of climate change in regions in Senegal and Zimbabwe attests to the importance of engaging stakeholders so as to reduce uncertainty in scenario results. The Senegal team used model-based projections of price and productivity trends, while the Zimbabwe team used price and productivity trends estimated from interactions with stakeholders and local experts. The results for Senegal show a larger variability in the range of net economic impacts and also a much larger positive impact of improved socioeconomic conditions in the future. In the case of Zimbabwe, direct interaction with farmers improved the precision of estimates (i.e., it reduced uncertainty) and facilitated a more realistic assessment of the possibilities of improved socioeconomic conditions.[22]

Preliminary analyses of adaptation strategies for some of these regions also show that there are substantial opportunities to offset the adverse impacts and enhance the beneficial effects of climate change (Rosenzweig and Hillel, eds., 2015), pointing further to the usefulness of integrated climate impact assessments when they are designed in collaboration with stakeholders. With regard to the Nkayi region of Zimbabwe, scenarios built in collaboration with stakeholders have made it clear that asset ownership is an important contributor to an understanding of the unequal effects of climate change and the effectiveness of adaptation strategies (box III.1). Scenario results show that without adaptation measures, farmers possessing cattle are more exposed, inasmuch as the main adverse impact of climate change is not on crops but on livestock feed availability and livestock productivity. However, farms without cattle are poorer and more dependent on a single source of farm income, and are thus more vulnerable to climate change. Indeed, in the absence of adaptation, the impact of climate change will be relatively greater on farms with no cattle. With adequate adaptations in farming, and once account is taken of the factors that determine differential levels of exposure and vulnerability across the spectrum of farmers, the simulated scenarios yield substantial impacts on per capita incomes, significantly increasing the incomes of the poorest farmers. These results point to the importance of engaging with stakeholders, particularly communities (in this case, farm communities), to uncover the aspects of poverty and inequalities that are relevant for modelling analysis and for consideration of policy options.

Challenges going forward

Inequality analysis is a central component of climate impact assessments; and feedback from stakeholders is critical to design and assessment of the scenarios that underpin it

This chapter has described how integrated climate impact assessments can assemble different modelling frameworks to generate an understanding of the economic, social and environmental challenges posed by climate hazards to exposed and vulnerable people and the policy options available to confront those challenges. Several suggestions have been made on how to broaden the analytical scope of those assessments along different lines, for example, through incorporation of adaptation, resilience, and climate hazards (including extreme events). It is also critical to consider the economy-wide feasibility of policies for climate resilience, especially given that, as discussed further in chapter V, bridging the financial gaps in adaptation presents a particular challenge going forward. Putting inequalities at the forefront of these assessments is an essential means of shifting the focus of attention towards the very core of the climate change adaptation challenge. To this end,

22 See Antle and Valdivia (2016) for an integrated presentation of results derived from the regional studies presented in Masikati and others (2015) and Adiku and others (2015).

Box III.1

Climate change and adaptation strategies in the Nkayi region of Zimbabwe

The regional integrated assessment (RIA) framework of the Agricultural Model Intercomparison and Improvement Project (AgMIP) was applied by a research team in Zimbabwe, with the aim of generating information on adaptation strategies for crop-livestock systems in the Nkayi region (Masikati and others, 2015). The research process was conceptualized as a long-term dialogue for co-learning, where researchers interacted with stakeholders in exploring and designing alternative sets of plausible future scenarios and climate change adaptation packages for integrated modelling (Homman-Kee and others, 2016; and Homman-Kee and others, forthcoming). Different adaptation options in maize farming for particular farm types and entire communities were assessed through integrated modelling.

Table III.1.1 summarizes research results that have been used in an economic analysis of climate change impacts for the Nkayi farm population, as stratified into three groups: farms without cattle; farms with less than eight heads of cattle (small herd); and farms with more than eight heads of cattle (large herd). Without adaptation, vulnerability to loss from climate change ranges from 45 per cent of farm households without cattle to 61 per cent and 71 per cent of households with small and large herds, respectively. The households with cattle are more exposed because the main adverse impact of climate change is found to fall on livestock feed availability and livestock productivity. Losses range from 25 to 57 per cent of mean farm net returns before climate change, which is a substantial figure for the vulnerable households. However, some farms benefit from favourable biophysical and economic conditions, with gains ranging from 28 to 34 per cent of mean returns before climate change. The net impacts aggregated across all farms are positive but small for farms without livestock, and much larger but negative for farms with large herds. Even though the losses represent a larger proportion of farm income for the farms with cattle, the farms without cattle are much poorer. Thus, with climate change, the negatively impacted farms without cattle will be in an even worse-off condition than before climate change and much poorer than the farms with cattle.

"Adopters" generally reap greater farm net returns compared with "non-adopters". Farms without cattle are very likely to adopt the adaptation measures being considered, with adoption rates of about 96 per cent under the rapid adaptation scenario and over 75 per cent under the transitional adaptation scenario, where the benefits are realized more gradually, over 10 years. While these farms gain relatively more (as a percentage of their farm income) than farms with cattle, they do not necessarily gain more in absolute terms because of their much lower incomes. The reason for the relatively smaller impact of climate change on farms without livestock and their greater benefit from adaptation is that the adaptations under analysis result in a greater improvement in crop productivity than in livestock productivity. The adaptations have substantial impacts on per capita incomes, more than doubling the farm incomes of the poorest households.

In this analysis, resilience is defined as the capability of a system to minimize the magnitude of adverse impacts or enhance positive effects. Resilience analysis considered two adaptation scenarios: transitional adaptation, where farmers need five years to realize the full benefits of the practices (owing, for example, to learning requirements) and rapid adaptation, where farmers realize the full benefits immediately. As the rapid adaptation scenario is interpreted as entailing minimum loss, resilience is in this case 100 per cent. The no-adaptation and transitional adaptation cases are evaluated relative to the rapid adaptation case. The analysis considers the benefits over a 10-year period, using a discount rate of 10 per cent.

Under these assumptions, the no-adaptation scenario assigns to the farms without cattle a resilience of 91 per cent, a figure that is somewhat higher than that for the resilience of the systems with cattle (both small and large herds) (79 per cent). With the adaptation package,

(*continued*)

Box III.1 (*continued*)

Table III.1.1
Vulnerability, resilience and net economic impacts of climate change projected until 2050 for crop-livestock systems in Nkayi, Zimbabwe, without and with adaptation scenarios

Percentage

			Climate impact on net returns				Adoption of adaptations	
Stratum	Adaptation	Vulnerability	Gains	Losses	Net impact	Resilience	Adoption rate	Adopter gain
No cattle	None	45	28	-25	3	91	-	-
No cattle	Transition	18	73	-32	41	93	75	60.5
No cattle	Rapid	1	139	-20	119	100	96	136
Small herd	None	61	32	-41	-9	79	-	-
Small herd	Transition	39	42	-33	9	93	80	20
Small herd	Rapid	25	51	-27	24	100	98	51
Large herd	None	71	34	-57	-23	79	-	-
Large herd	Transition	46	47	-42	5	98	64	43
Large herd	Rapid	42	48	-40	8	100	80	87

Source: Antle and Valdivia (2016).
Note: Transitional adaptation occurs over five growing seasons, rapid adaptation in the first growing season. Gains, losses and gains to adopters are expressed as a percentage of mean farm net returns before climate change. Vulnerability is defined in terms of the proportion of households that are at risk of losing net returns and resilience in terms of the proportion capable of minimizing the magnitude of adverse impacts or enhancing positive effects. Antle and Valdivia offer more precise definitions.

these resilience factors are improved substantially. This analysis thus illustrates the potential benefits of enhancing the adaptive capability of farmers, thereby enabling them — when effective adaptation options are available and can be readily adopted — to reduce vulnerability substantially and enhance resilience.

it has been suggested that different modelling frameworks should be integrated in response to the specific policy questions confronting each country, depending on data availability. Improved use of integrated modelling frameworks along these lines will contribute to the assessment of the impacts of climate hazards and policies relating to:

- Climate-sensitive natural resources upon which livelihoods rely, using biophysical models
- Distribution of income on the basis of ownership and employment of production factors (land, capital, labour), using economy-wide models
- Human capital and access to basic public services and resources (education, health, sanitation, infrastructure), using economy-wide models
- Vulnerabilities of disadvantaged groups that are defined based on a configuration of socioeconomic attributes, explored through more intensive use of household surveys and microsimulation analysis

In view of the inherent limitations of any modelling exercise, engaging different stakeholders (including policymakers, experts and communities) is an important means of procuring the sort of detailed information and feedback that are critical to the design of model-based scenarios and reassessment of those scenarios and their results. The meaningful participation of stakeholders assures the input of local political and expert judgment. The feedback of vulnerable population groups and communities is particularly important for achieving an understanding of the factors that exacerbate people's exposure and vulnerability to climate hazards, including how those factors may relate to structural inequalities as people experience them. It is also important when assessing adaptation options to ensure that they are made relevant to the building of climate resilience among people and communities.

Extending the use of climate impact assessments requires improved information systems, improved technical expertise and strengthened governance...

It is indeed regrettable that not all developing countries are in a position to apply integrated climate impact assessments at the level of detail needed to inform policy. Some countries are using partial quantitative assessments, qualitative evaluations and expert judgment to promote an understanding of the links between climate and socioeconomic conditions, which represents a good starting point. Many countries conduct at least a household survey which, as noted, can be highly instrumental in identifying drivers of households' exposure and vulnerability which provide a basis for analysing policy options. However, these partial approaches, unlike integrated climate impact assessments, cannot fully capture the interlinkages among the different aspects of development that are important in assessing the policy options for building climate resilience and achieving sustainable development that are available to countries. Extending the use of integrated climate impact assessments to inform policy in developing countries requires dedicated efforts in three areas: (a) improving basic information systems and statistics, (b) building countries' capacity to construct and use modelling tools for integrated assessments and (c) strengthening institutional capacities to support evidenced-based policymaking and implementation, including the use of integrated assessments as part of policy decision-making processes, with proper dissemination of results, and stakeholders' engagement in the assessment of policy options.

...which in turn requires international collaboration on bridging gaps at the country level

With regard to data and statistics at a level that is more macro in character, there is a gap in environmental accounting and climate-related statistics and indicators. Nevertheless, the United Nations, other multilateral institutions and countries themselves have already started making headway in this area. It is at the micro level, however, that the most critical information gap exists. Information to help identify characteristics of vulnerable populations at the local level in developing regions, where adaptation is most needed, is lacking (see chap. V). The regional studies developed by the AgMIP project, as noted above, relied on their own farm surveys in different regions because that type of information is not collected under standardized processes. There is also limited access to other important sources of information (e.g., global climate projections, geographic information systems, visualization of sea level and forest coverage). Collaboration with the international statistical community will play a fundamental role in building new and assessing existing data and statistical capacity (see chap. V).

Building capacity to construct and use integrated assessments at the country level is also important. While greater efforts are needed to improve the production of data and statistics, it is also true that existing information is underutilized. As noted above, a large number of countries have at least one household survey which can be used to address issues related to vulnerability and inequality at some levels of disaggregation that are relevant to support of development policies (United Nations, 2016). Modelling capacities should also be strengthened in areas where information exists. For example, crop simulation models, which are used extensively in climate change studies, are not widely used in developing countries. White and others (2011) examined 211 peer-reviewed papers that used crop simulation models to examine different facets of the question of how climate change might affect agricultural systems. The main focus of those papers (approximately 170) was the response to climate change of producers of wheat, maize, soybean and rice. The United States of America (with 55 papers) and Europe (with 64 papers) were the dominant regions studied.

Scenario-building that supports policymaking and implementation requires procedural stability, and permanent yet flexible institutional and governance structures which build the trust and experience needed to take advantage of new insights for effective and fair risk management (Volkery and Ribeiro, 2009). This includes institutionalizing the use of the integrated analytical framework within government, using scenario results to inform policymaking and propel policy implementation; coordinating and mobilizing technical expertise across sectoral ministries; and working with stakeholders and researchers at all levels. In other words, what is required are changes in the policy system (see chap. IV).

Timely, fluent and effective communication of climate impact assessment results improves understanding of the policy options available for building resilience

Communicating the results of integrated climate impact assessments, within government and to stakeholders at large, is another area where improvement is needed. Timely, fluent and effective communication of those results is critical to improving understanding of the multiple interlinkages that exist across the different dimensions of development and the policy options available for building resilience. A wider communication of results is an instrument that is useful in engaging multiple stakeholders in policy dialogues oriented towards identifying priorities based on informed options. Finding adequate communication mechanisms that help influence behaviour for reducing the risk of maladaptation is also important (see chap. IV).

Translating, reporting and communicating results through user-friendly visualizations are grounded in statistical techniques, which also require capacity-building efforts. Along the same lines, broad dissemination channels (e.g., television, radio and Internet broadcasts, blogs and high-level summits) constitute a useful means of creating widespread awareness among the general public. Evidence from the Advancing Capacity for Climate Change Adaptation (ACCCA) project, UKCIP (formerly known as the United Kingdom Climate Impacts Programme) and IPCC (2012) suggests that these broad communication channels do work. Indeed, interactive strategies, group discussions, workshops and user-friendly and visually appealing documentation will be critical tools for communicating and working with stakeholders and researchers at the local level. Such outreach mechanisms for communicating scenario results are learning and discussion platforms which serve to facilitate knowledge exchange and adaptation. Information can then be shared through wider networks and in turn exert an influence on action, thereby enabling the conduct of new experiments and engagement in new practices which can in turn strengthen systemic resilience (Ospina and Heeks, 2010).

The support of the international modelling community for the process of strengthening the use of integrated climate impact assessments will be important with regard to improving coordination across the spectrum of communities involved in the generation of those assessments at the global level, so as to make them more accessible to Governments and researchers in developing countries. This will include the development and transfer of new modelling tools and climate data as well as protocols, based on rigorously documented methodologies, that are available to the public. These protocols will be critical to replicating and comparing results, improving methods over time, linking results to “knowledge products” that improve their usability among policymakers and stakeholders, and increasing the credibility of assessments.

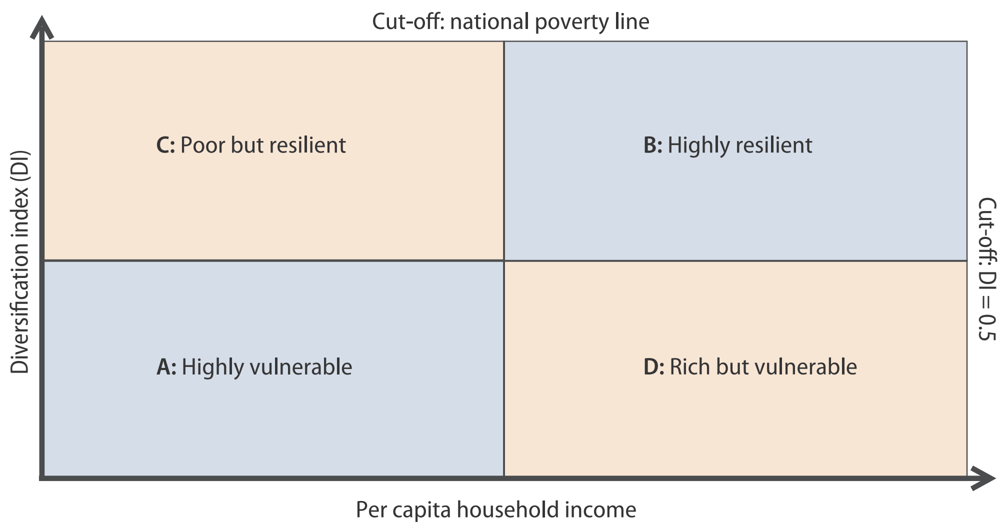
Consistent with the commitment under the 2030 Agenda for Sustainable Development to the strengthening of the science-policy interface and the development of evidence-based instruments to support sustainable development policymaking, United Nations entities and other multilateral and bilateral organizations can play an important role in improving coordination among the members of the international modelling community and in strengthening countries' capacities to bridge modelling-related gaps. At the same time, it is important that Governments themselves liaise more with the researchers engaged in smaller, often community-based integrated assessment projects, where results can be gathered within relatively short time frames and direct interactions among researchers, stakeholders and policy implementation agencies are a common practice.

Appendix III.1

Determinants of vulnerability and resilience: a household survey-based analysis

The identification of vulnerable households can be made through household surveys, with the starting point being a concrete and practical definition of vulnerability. The work of Andersen and Cardona (2013) is drawn upon here for purposes of illustration. The most vulnerable households are those that, simultaneously, have low levels of per capita income and low levels of diversification as a result of which any adverse shock will threaten their entire income base. A household that has a per capita income below the national poverty line and a diversification index (DI) of less than 0.5 is classified as highly vulnerable; households above these thresholds are classified as highly resilient (figure A.III.1).

Figure A.III.1
The four main vulnerability types as constructed by Andersen and Cardona (2013)



Source: Andersen and Cardona (2013).
Abbreviations: DI, diversification index.

Since diversification is the opposite of income concentration, a simple and logical way of constructing the diversification index is simply as 1 minus the widely used Herfindahl-Hirschman index of concentration, whereby

$$\mathrm{DI} = 1 - \sum_{i=1}^{N} p_i^2,$$

where N is the total number of income sources and p_i represents the income proportion of the ith income source. The value of the index is 0 when there is complete specialization (100 per cent of total household income comes from one source only) and approaches 1 as the number of income sources increases and no single source dominates household incomes.

Both measures of vulnerability—the diversification index and per capita household income—can be calculated for each household using a standard household survey and can be aggregated to any group or socioeconomic characteristics of interest. This makes it possible, through econometric analyses, to establish the determinants of vulnerability and resilience which in turn allows the types of households most likely to be vulnerable to shocks to be identified.

This type of analysis has been applied using the 2011 household survey carried out by the National Statistical Institute of the Plurinational State of Bolivia. Income per capita and the diversification index are estimated for each household. Based on these two variables, two dummy variables are constructed to indicate whether a household belongs to the highly vulnerable group (incomes below the poverty level and DI<0.5) or the highly resilient group (incomes above the poverty level and DI>0.5). The factors and characteristics most strongly associated with vulnerability and resilience are determined through probabilistic (probit) regression.

This analysis shows that the most important determinant of vulnerability and resilience in the Plurinational State of Bolivia is the presence of a working spouse in the household (table A.III.1). This reduces the probability of being highly vulnerable by 12.2 percentage points and increases the probability of being highly resilient by 31.2 percentage

Table A.III.1
Probit regressions demonstrating the factors associated with vulnerability and resilience in the Plurinational State of Bolivia, 2011

Independent variable	Vulnerability regression	Resilience regression
Years of education of head of household	-0.004	0.002
	(-5.15)	-2.14
Number of persons in household	0.027	0.012
	-15.7	-4.34
Urban dummy	0.043	0.026
	-5.65	-2.06
Age of head of household	-0.005	0.01
	(-19.85)	-26.3
Female head of household dummy	-0.005	0.016
	(-0.52)	-1.25
Indigenous dummy	0.027	-0.077
	-3.31	(-6.61)
Dependency ratio	0.019	-0.015
	-7.9	(-4.69)
Remittance dummy	-0.07	0.12
	(-6.69)	-5.04
Public sector dummy	-0.059	0.087
	(-6.37)	-5.37
Working spouse dummy	-0.122	0.312
	(-18.21)	-27.39
Number of observations	***8848***	***8848***
R^2	***0.148***	***0.1747***

Source: Andersen and Cardona (2013).

Note: The numbers in parentheses are z-values.

points. However, only about one third of Bolivian households use this strategy, as there is still a strong traditional belief that married women should dedicate their time to child-rearing and domestic chores. According to the analysis, this is the single most important factor associated with high vulnerability in the Plurinational State of Bolivia.

The age of the head of household is the second most important determinant of vulnerability and resilience. The older the head, the lower the probability of being vulnerable, and the higher the probability of being resilient. Adding 20 years reduces the probability of being in the highly vulnerable category by 10 percentage points and increases the probability of being highly resilient by 20 percentage points. This is a natural life-cycle effect: young families have not had time to build a supply of assets which can provide supplementary income (such as rental income) and at the same time they often have young children to care for. In this context, very young families are of particular concern. According to the survey, there are more than 30,000 families with children in which the head of household is no more than 20 years old, of which 46 per cent are highly vulnerable. In more than 11,000 of these very young households, there are already two or more children. The probability of being highly vulnerable is 59 per cent for this group and the probability of being highly resilient is less than 2 per cent. This kind of situation can be prevented by better family planning education and support.

The next most important determinants of vulnerability are remittances and having a public sector job, both of which reduce the probability of falling into vulnerability by about 6 or 7 percentage points. Other important determinants include number of persons in the household and belonging to an indigenous population group.