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Climate change resilience — an opportunity for reducing inequalities

BACKGROUND PAPER

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# Analytical dimensions of inequality in integrated climate impact assessments

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**Summary:**

Integrated climate impact assessments help to inform the discussion of impacts of climate change and policy options to address them. The integration of biophysical and socio-economic models made it possible to move from an analysis purely focused on physical effects to one that also accounts for the prospective long-term effects on human welfare. There is a better understanding of the effects of climate change on poverty and livelihoods. The nexus between climate change and inequality has, however, remained under-researched or inadequately studied. Not only is inequality closely associated with poverty and livelihoods and is rising within many countries but, importantly, structural inequalities are a fundamental determinant of exposure and vulnerability to climate change. This paper suggests ways of deploying existing modelling frameworks to explore four potential sources of inequality in integrated assessments: (i) climate-sensitive natural resources upon which livelihoods rely, using biophysical models; (ii) distribution of income on the basis of ownership and employment of production factors, using economy-wide models; (iii) human capital and access to basic public services and resources, using economy-wide models; and, (iv) socioeconomic attributes, explored through household survey and microsimulation analysis.

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# 1. Introduction

The discussion of impacts of climate change was originally focused—and remained focused for quite some time—on the physical impacts. In recent years, however, more serious attention has been paid to quantify the prospective long-term effects of climate change on human welfare. It took some time for researchers across different disciplines to develop and test the methodological tools that made it possible to broaden the focus of the analysis of climate change so as to include socio-economic impacts. New evidence emerged as studies began to combine different modelling techniques to look at the biophysical and socio-economic impacts of climate change in an integrated manner. These studies are commonly regarded as integrated climate impact assessments, or integrated assessments for short.

Different reports began to document the considerable research, including from integrated climate impact assessments, that was being devoted to understanding the socio-economic impacts of climate change.[1] The World Health Organization (WHO) addressed the potential health impacts of climate change as early as 1989 (WHO, 1990); however, it was until the 2000s that reports and studies began to generate broader evidence of the effects of climate change on poverty and livelihoods (e.g., World Bank, 2002, 2008; Stern, 2006; Carvajal-Velez, 2007; Brainard and others, eds., 2009; UNECA, 2010; Hughes and others, 2012; Skoufias, 2012; among others). Research subsequently moved to investigating the mechanisms through which the effects of climate change on poverty and livelihoods work in practice. Hallegatte et al. (2014), for example, identify prices, assets, productivity and opportunities as four critical channels through which households may move in and out of poverty in the presence of climate change. In their contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Olson and others (2014) provide an extensive review of statistical and anecdotal evidence regarding the dynamic interaction between climate change, poverty and livelihoods. More recently, Hallegatte et al. (2016) examine the magnitude of future climate change impacts on poverty as these are channelled through food prices and production, natural disasters, health and labour productivity.

The nexus between climate change and inequality has remained relatively under-researched though, in spite of the fact that inequality is closely associated with poverty and livelihoods, the dramatic increase in income inequality in many countries in the past decades, and, importantly, the fact that inequalities are a fundamental determinant of exposure and vulnerability to climate change. According to IPCC (2014c), exposure refers to the presence of people (including their livelihoods), ecosystems and species, or economic, social, or cultural assets in places that could be adversely affected by climate hazards. Vulnerability is defined as the propensity or predisposition to be adversely affected, which encompasses sensitivity or susceptibility to harm and lack of capacity to cope and adapt. Conforming to these definitions, exposure and vulnerability are determined implicitly by the conditions of poverty, marginalization and social exclusion as they affect specific population groups.

[1] For a comprehensive review of studies addressing the association between climate change and socio-economic inequality see, Islam and Winkel (2016).

Only recently has the role of inequality in understanding the impacts of climate change been gaining more recognition. Skoufias (2012) note the regressive nature of climate change impacts in the context of Brazil where these impacts tend to affect relatively more the poor than the rich. Olson and others (2014: p. 796) argue that "socially and geographically disadvantaged people exposed to persistent inequalities at the intersection of various dimensions of discrimination based on gender, age, race, class, caste, indigeneity, and (dis)ability are particularly negatively affected by climate change and climate-related hazards." Disproportionate erosion of physical, human, and social assets as a result of climate change and climate-related hazards exacerbates inequalities and place these people even at more disadvantage (ibid.).

Nonetheless, determining whether inequalities shape differential vulnerabilities to climate change has not been a central concern in studies making methodological contributions for addressing the nexus between climate change and equity. In these studies equity considerations are limited to the analysis of the "social cost of carbon"—the expected present-value damages arising from carbon dioxide (CO2) emissions. 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" this 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 equity 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. 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). These approaches to equity, while representing methodological advances, are still inadequate for the purpose of tracing impacts on the specific groups that are particularly vulnerable to climate change and climate-related hazards.

Not surprisingly, Olson and others and other contributors to the IPCC Fifth Assessment Report raise the concern that few assessments examine how inequalities shape differential vulnerabilities to climate change. Chambwera and others (2014) report 13 economic assessments of adaptation options, spanning the period from 2006 to 2013. A close review of these assessments for this paper corroborates the observation that inequalities do not feature prominently in their analysis (see Appendix 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 provide 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 inequality; and another study considered inequality only contextually.

In sum, there is a serious gap in addressing inequality in the literature related to integrated climate impact assessments. This paper suggests ways of deploying existing modelling frameworks to explore inequality more prominently in integrated assessments that are not exclusively focused on quantifying the impacts of climate hazards on people, but also the impacts of policies intended to build climate resilience for those mostly affected.

The remainder of the paper contains four more sections. Section 2 describes the integration of modelling tools in climate impact assessments as it is mostly applied in practice. Section 3 subsequently discusses two areas where the scope of integrated assessments would need to be broadened to enable better analysis of inequality when using modelling tools. Firstly, 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. Secondly, there is a need to expand beyond a limited accounting of the costs and benefits of single mitigation policies by deepening the analysis of the broader economic and financial feasibility of policies for climate resilience. These two sections lay the ground work for understanding, in section 4, the ways in which modelling frameworks can be deployed to explore different dimensions of inequality. The final section concludes and sets out the key research challenges going forward to continue making inequality analysis a central part of integrated climate impact assessments.

## 2. Integration of modelling tools in climate impact assessments

The international community of natural and social scientists has adopted an integrated approach to climate impact assessments. This approach combines models from different disciplines aiming at generating scenarios on potential impacts of climate projections and policies options to address them, for the world as a whole and for smaller geographical levels.

These types of scenarios inform international climate discussions and feature prominently in supporting conclusions and recommendations in assessment reports of the IPCC (see, e.g., IPCC, 2014). Scenarios from integrated assessments are also used to develop narrative storylines which help decision makers in many countries plan policy interventions for reducing adverse impacts arising from a changing climate.

However, the different models that are featured at present in integrated climate impact assessments are not used to consider inequality as a potential source of exposure and vulnerability to climate change. Or, as noted above, existing quantitative approaches to study climate change with equity considerations are not equipped to trace impacts on specific groups that are particularly at risk in the face of climate hazards. Before elaborating on the capability of existing modelling frameworks to address inequality issues as they relate to climate change, it is first necessary to understand the sequence in which these frameworks are most typically integrated to develop assessments. Discussing the methodologies by which these modelling frameworks can be integrated with one another (that is, potential soft- and hard-links among them) is however beyond the scope of the paper.

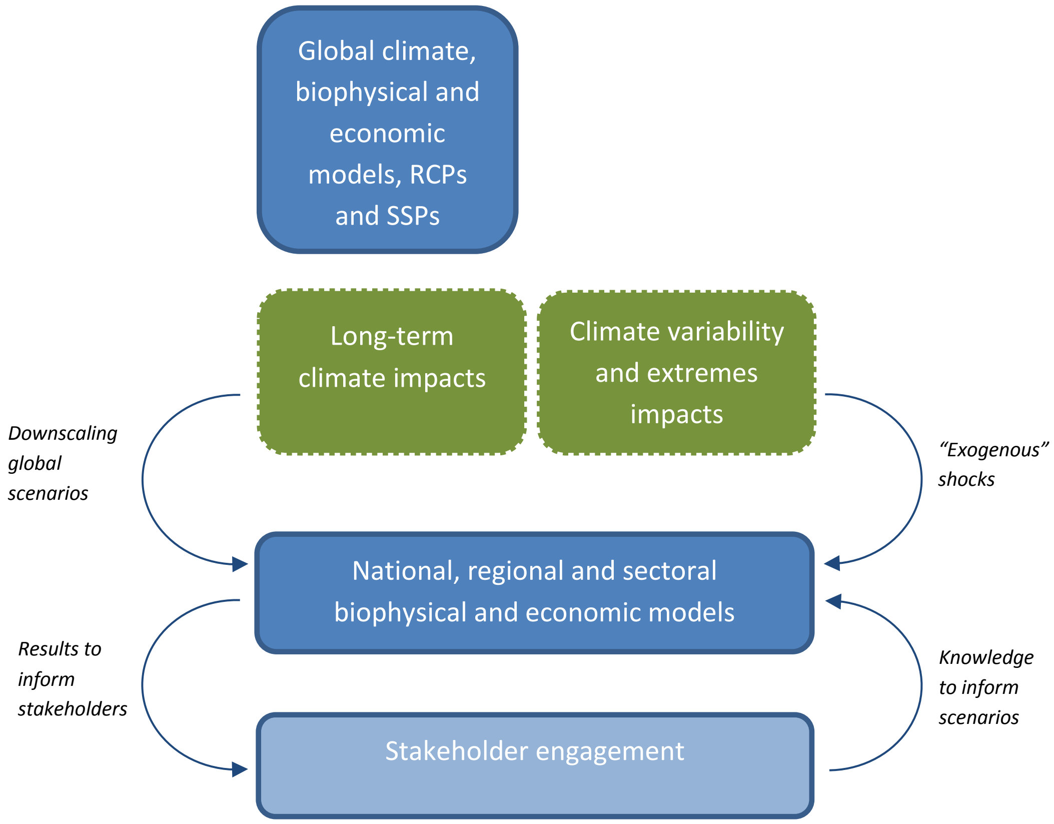
The tendency has been to integrate models to assess long-term climate change impacts and climate policy responses following the steps described in Appendix 2. Nonetheless, there is modelling capability to assess short-term risks, too. Figure 1 provides a simplified representation of the cascade of analytical steps taken in integrating modelling frameworks to assess short-terms risks and long-term impacts. For illustration purposes, the figure also depicts 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, key aspects of any climate impact assessment looking at inequalities, as further explained below.

Global climate models, also known as global circulation models (GCMs), are generally used to project climate changes, typically changes of temperature and precipitation patterns, over relatively large spatial and temporal scales. These projections are influenced by different scenarios, for the world, of greenhouse gas (GHG) 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 presents evidence emanating from biophysical models suggesting that climate change impacts are strongest and most comprehensive for natural systems (IPCC, 2014c, p. 4).

Global economic models as subsequently incorporated to generate scenarios that translate changes in natural resource systems into changes in socioeconomic ones. At this step, shared socioeconomic pathways (SSPs) 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.

**Figure 1 Simplified representation of the integrated approach to climate impact assessments**




Source: Author's construction.

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 generated and assessed at both global and lower geographical levels, additional scenarios can be run at any of these levels 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, among others. With regard to the 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.

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",[2] 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 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.

## 3. Key areas for broadening the scope of the modelling analysis

Adapting to climate change and building climate resilience in the face of climate hazards require integrated assessments that help identify inequalities that fundamentally determine exposure and vulnerability to climate hazards and assess policy options to address these structural factors behind such inequalities. Integrated climate impact assessments have, however, been focused more on mitigation and long-term climate change. Less attention has been paid on the impact of climate hazards arising from climate variability and extreme weather events, which is what people most feel, and on the policy options for adaptation and resilience.

The focus on mitigation is to a large extent comprehensible because there is difficulty in measuring adaptation. The concepts of adaptation and resilience have no common reference metrics comparable to the ones that exist for mitigation; i.e., tons of greenhouse gases and radiative forcing values. Measuring adaptation and resilience would require a larger number of development indicators relevant to each country and specific local context (Noble and others, 2014).

Nevertheless, the lack of common reference metrics for adaptation and resilience need not hinder analysis of those processes through integrated assessments. 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, better educational services, and so forth. Any analysis that integrates those goals and examines potential policies to achieve them 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.

[2] 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).

There is ample evidence of the severity of impacts from climate extremes and variability on people and livelihoods (Smith and others, 2009). 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 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.

Another important aspect to keep in mind is the feasibility of the policy options. Socioeconomic modelling is used in integrated assessments typically to produce a standard accounting of the costs and benefits of climate policy. There has been a tendency to use economic models that are aggregate and simple in terms of their data requirements and estimation techniques because typically the costs and benefits are accounted for a single project or intervention.[3] However, it is important to broaden the scope of the modelling analysis to encompass not just a simple cost-benefit analysis of a single policy, but also the economy-wide repercussions and macroeconomic feasibility of multiple policies, including those towards broader development, which requires the use of more comprehensive modelling approaches. This is particularly important if there are gaps in the financing of adaptation and a necessity to scale up multiple investments in order to build 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.[4] Other economic models (e.g., microeconomic structural and land-use models) do allow for changes in resource allocation but lack details 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.[5] 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

[3] 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.

[4] 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.

[5] 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.

the economy. This would represent a case of what can be called policy incoherence or maladaptation.

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 all markets and the macroeconomic constraints. Economy-wide models that are also known as computable general equilibrium (CGE) models very well meet these characteristics. 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, for example of a climate-related events or any policy change or exogenous shock that work through the different markets of the economy (e.g., factors, commodities and foreign exchange), under given macroeconomic constraints. If need be, CGE and PE models can be part of the same integrated assessment.

## 4. Analytical dimensions of inequality in modelling frameworks

With the considerations above in mind, it is possible to deploy different combinations of modelling tools to explore four analytical dimensions of inequalities in integrated climate impact assessments. Table 1 presents four sources of inequalities and the modelling frameworks that make it possible to analyse each one of them. The remainder of this section discusses each analytical dimension in detail. 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.

**Table 1: Sources of inequality in modelling frameworks**

<table>
<tr><th>Sources of inequality</th><th>Modelling approach</th><th>Strengths of modelling approach</th><th>Weaknesses of modelling approach</th></tr>
<tr><td>Livelihoods relying on climate-sensitive natural resources</td><td>Biophysical modelling</td><td>Detects impacts on livelihoods that depend on climate-sensitive natural resources<br><br>Detects how changes in one natural resource may impact other natural resources<br><br>Suggests how natural resources can be allocated more efficiently for adaptation</td><td>Relies on assumptions about behaviour without incorporating behavioural change, which is critical for climate change adaptation<br><br>Changes in natural resources are not fully translated into socioeconomic changes<br><br>Does not specify effects on the livelihoods of disadvantaged groups in particular<br><br>Data-intensive</td></tr>
<tr><td>Ownership and employment of production factors</td><td rowspan="2">Economy-wide modelling</td><td rowspan="2">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.<br><br>Can include human development indicators as a function of socioeconomic determinants, including public investments in social sectors and infrastructure</td><td rowspan="2">Relies on assumptions regarding behaviour without incorporating behavioural change, which is critical for climate change adaptation<br><br>Because of the aggregation of representative household groups, estimates of changes in income distribution may be biased<br><br>Limited with respect to addressing other forms of primary inequality beyond income<br><br>Data-intensive</td></tr>
<tr><td>Human capital and access to public services and resources</td></tr>
<tr><td>Socioeconomic characteristics at the household level</td><td>Microsimulation modelling (with household surveys, preferably linked to economy-wide model)</td><td>Adds value in identifying vulnerability associated with socioeconomic characteristics (e.g., gender, age, race, religion and ethnicity) whose intersection defines inequalities<br><br>Points to policy options for reducing vulnerability<br><br>Less data-intensive when at least one household survey is available</td><td>Relies on assumptions about behaviour without incorporating behavioural change, which is critical for climate change adaptation<br><br>Limited analysis of financial feasibility of policies—when not combined with economy-wide model<br><br>Depends on the quality and coverage of household surveys</td></tr>
</table>

Source: Author.

**Livelihoods and climate-sensitive natural resources**

Livelihoods that depend on climate-sensitive natural resources, such as land, water and energy, are exposed to climate hazards. 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 representing 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 find 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.[6]

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.[7]

The International Renewable Energy Agency (IRENA) (2015) reports the noteworthy findings derived from a number of exploratory case studies on the Water-Energy-Food Security Nexus. One study shows 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 demonstrates that, in India, where nearly 20 per cent of electricity-generation capacity is used for agricultural water pumping, lower-than-usual rainfall accompanied by

[6] 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.

[7] Welsch and others (2014) demonstrate the advantages of analysing energy pathways by integrating natural resource systems—using the CLEWs framework—rather than using an energy systems model alone, given the importance of decreasing rainfall and future land-use changes.

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, leaving the poorest farmers far behind.

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 GHG 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 shows that 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 GHG–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. In this case, 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 repercussions). The CLEWs analysis has prompted the Government of Mauritius to start thinking about how to adapt to these challenges.[8]

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 may be affected. However, identification of the specific distributional impacts of climate hazards

[8] 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).

and the policy options available to offset them would require additional socioeconomic analysis.

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. This methodological gap can be bridged by adding analysis with socioeconomic modelling frameworks. 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 different factor endowments, these being labour, land or capital. Climate hazards have disproportionate impacts on the limited assets of disadvantaged population groups when they cause a disruption of economic activity and 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 or 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 climate 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—alone or in combination with other type of economic models.

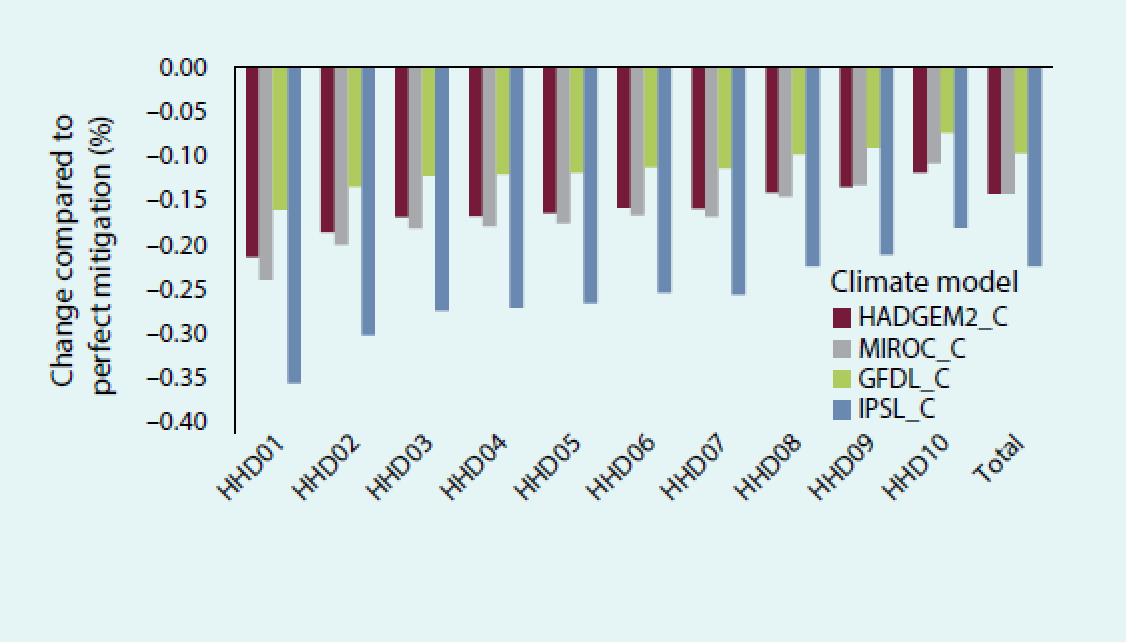
Several examples help illustrate the functionality of the economy-wide modelling framework. Appendix 3 presents the summary of an assessment of climate shocks for the Plurinational State of Bolivia. In a nutshell, the analysis shows that a reduction in labour productivity as a result of the impact of rising temperature on workers' health, or a destruction of public infrastructure by 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 possibility that some policy options may have unintended consequences, as in this example, points to the importance of analysing the macroeconomic feasibility of policies for climate resilience.

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 (Appendix 3) 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 2).

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.

**Figure 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 (Percentage)**




*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 to analyse the income effects.

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.[9] 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

[9] 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.

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

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. 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, some of which find that climate change for example reduces life expectancy, in Peru (Andersen, Suxo and Verner, 2009); depresses people's incomes, in Chile (Andersen and Verner, 2010); and encourages 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 through hewing to the contours of economy-wide modelling.[10] 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.[11] 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, only few economy-wide analyses with these characteristics examine climate policies.

For example, an economy-wide analysis for Bolivia (Plurinational State of), Costa Rica and Uganda presenting such characteristics explores the scope for scaling up public investments in human development by raising public revenue through an implicit carbon tax

[10] 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.

[11] The *Maquette* for MDG Simulations (MAMS) is a dynamic–recursive, Computable General Equilibrium (CGE) model that meet these characteristics. For more details on this model see, Lofgren, Cicowiez and Díaz-Bonilla (2013).

(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 be offset by increasing investments in public infrastructure in transport and electricity (that indirectly enhances access to and functionality of schools or health centres) or, alternatively, in the building of public schools. The overall economy-wide impact of a carbon tax to finance these 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 scenarios can inform decision-making processes through exploration of options for building development policy coherence by pursuing the simultaneous objectives of reducing GHG 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 demonstrate 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 (MDGs) (Sánchez and others, 2010; Sánchez and Vos, 2013).[12] 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 climate resilience through improved access to basic public services without jeopardizing economic growth and macroeconomic stability.

Another inter-temporal trade-off is that most human development investments pay off in the long term, so the impact on inequality may come with an important lag. Sánchez and Cicowiez (2014) use an economy-wide model to estimate that past investments in education, health, water and sanitation during the period in which the MDGs were implemented, could lead to GDP growth gains in the range of 0.2-1.0 percentage points between 2015 and 2030. These authors also find that these potential long-term payoffs would be larger had the economies been more capable to absorb the new human capital. It would have been difficult to arrive at these policy insights without deploying an economy-wide model with human development dimensions.

**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. Analysis conducted at the micro level using household surveys adds value in terms of identifying households whose exposure and vulnerability are determined by specific socioeconomic characteristics.

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

Such an analysis need not be complex: it can rely on a single household survey and a simple definition of vulnerability; or, when various comparable surveys are available, the analysis can be developed using a panel of these surveys. Andersen and Cardona (2013) use 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, they find that the households that are particularly at risk of being vulnerable are 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. Using a panel of data from the Ethiopian Rural Household Survey (1994-2004), Dercon, Hoddinott and Woldehanna (2005) find that female-headed households are particularly vulnerable to drought-induced shocks.

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, shows that, although the transfer is not sufficient to ensure survival, it reduces vulnerability and increases resilience (table 2). When the monthly transfer is targeted specifically at people living in poverty, the transfer increases substantially (to Bs 175) without, however, increasing the total costs of the programme. Although the exercise considers neither the feasibility of financing such a programme nor the complexities of targeting, it does point to the potential effectiveness of the transfer in reducing vulnerability and increasing resilience.

**Table 2: 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 | 1360 | 14.9 | 33.5 |
| Citizen salary of Bs 80 per month per person | 1440 | 6.3 | 45.3 |
| Cash transfer of Bs 175 per month to all poor persons | 1428 | 3.7 | 44.1 |
| Prevention of all teenage pregnancies | 1464 | 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 4.

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).

Complementing this type of 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 the 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, including microsimulations, began to be reviewed (see van Ruijven, O'Neill and Chateau, 2015). On the other hand, some already existing studies provide interesting illustrations of the usefulness of this approach. Cicowiez and Sánchez (2011), for example, apply the approach to assess the impacts and feasibility of cash transfer programmes targeting households living in poverty in Latin American countries and in the face of economic shocks, including an increase in food prices (on which evidence shows climate change has impacts). They find that while these transfers lead unambiguously to a reduction in income inequality, financing and sustaining them under existing fiscal constraints depends largely on sustained economic growth.

Some of the other economy-wide analyses noted above have also been combined with microsimulations. The Bolivian analysis for instance finds that due to changes in the distribution of income across factors, the simulated climate shocks affect workers with adverse impacts on income poverty (see Appendix 3). In the studies of the other 27 developing countries also noted above, investments in human development, particularly in education, only usher in modest income inequality changes. In this case, the simulation period (2005-2015) is long enough to have observed a rising supply of skilled labour, with visible implications for income inequality. However, production technologies in most sectors of the economies remained fairly intensive in the use of semi-skilled and unskilled labour. Thus, the economies were not fully absorbing the growing numbers of skilled workers with the consequence that income inequality did not fall as expected—as Sánchez and Cicowiez

(2014) also find, as also mentioned earlier. The integrated analysis in this case underscores the necessity of accompanying human development investments with the necessary transformative changes that make it possible to productively employ new human capital and make it more resilient to economic shocks, including those caused by climate changes.

## 5. Conclusions and areas for further research

This paper has described how different modelling frameworks are deployed to put inequality at the forefront of integrated climate impact assessments. This is critical to address the very core of the climate change adaptation challenge: the fact that the exposure and vulnerability of disadvantaged population groups is shaped by inequalities. Several suggestions have been made to combine modelling frameworks with enough flexibility so as to: incorporate issues of adaptation and resilience, not only mitigation; assess climate hazards that afflict people in the short-term, not only in the long run; and consider the economy-wide feasibility of policies for climate resilience, not just the cost-benefit of a single policy often centred around mitigation. Modelling frameworks with these capabilities make it possible to improve the assessment of the impacts of climate hazards and policies that may potentially affect vulnerable population groups through changes in inequality associated with:

- 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; and,
- A configuration of socioeconomic attributes, explored through more intensive use of household survey and microsimulation analysis.

An important area for further research relates to the engagement of relevant stakeholders: that is, people and communities who can provide information and share knowledge regarding existing socio-economic factors that, they think, may be shaping inequalities that exacerbate their exposure and vulnerability to climate hazards. This feedback may be important to improve integrated assessments which can be used to ponder policy options that help address inequalities and thus increase the resilience of those people and communities.

Regional analyses of adaptation strategies show that there is potential to generate valuable information in this regard, for example on asset ownership which is a potential source of inequality. The regional integrated assessment framework developed by Agricultural Model Intercomparison and Improvement Project (AgMIP-RIA) 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).[13] Researchers interacted with stakeholders including farmers in exploring and designing alternative sets of plausible future scenarios and climate change adaptation packages for integrated modelling (Homman-Kee and others, 2016; and forthcoming).[14] 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. More research in this direction is necessary.

Important data and statistics gaps need to be bridged to facilitate the identification of the most vulnerable population groups and communities whose feedback on inequalities will be critical to improve integrated climate impact assessments. Information to help identify characteristics of vulnerable populations at the local level in developing regions, where adaptation is most needed, is lacking. There is no systematic data available on the size of the populations groups most vulnerable to climate hazards, including their demographic characteristics and their livelihoods.[15] 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.

[13] A detailed description of AgMIP-RIA can be found in Antle and others (2015).

[14] Antle and Valdivia (2016) have shown that this modality of engaging stakeholders has been important to reduce uncertainty in scenario results. They compare integrated assessments of climate change in regions in Senegal and Zimbabwe, using data from Masikati and others (2015) and Adiku and others (2015). 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.

[15] The challenge is even greater if one considers there are gaps even in more basic statistics. A World Bank study—referred to in United Nations (2015)—finds that almost half of the 155 countries examined lacked adequate data for monitoring poverty. Especially in sub-Saharan Africa, where poverty is most severe, 61 per cent of countries lacked data for monitoring poverty trends. Vital statistics disaggregated by geographical region, ethnicity, disability and other characteristics are also lacking.

## Appendix 1: The consideration of inequalities in economic evaluations of adaptation options

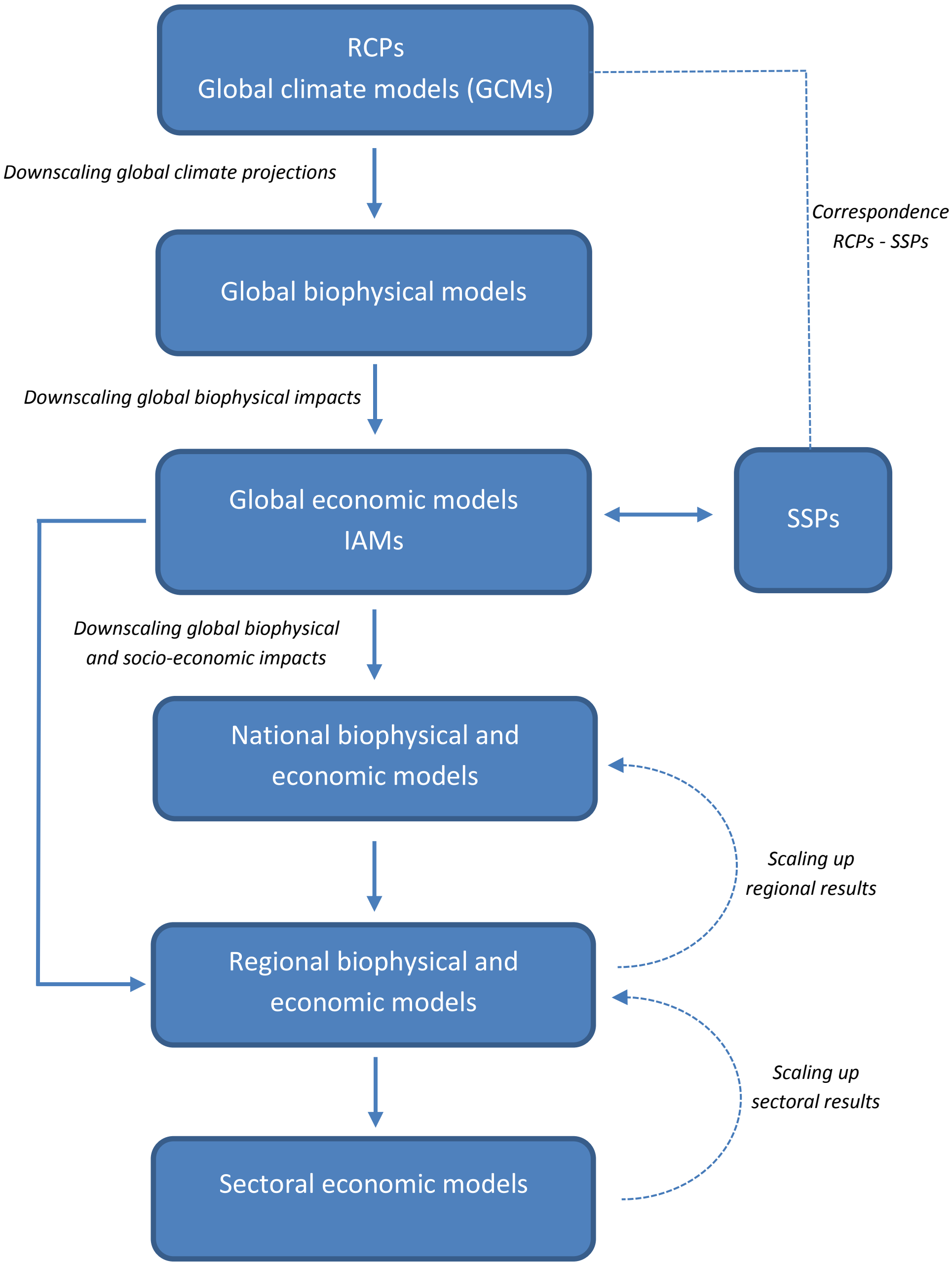
| Sector | Study, scope and methodology | Consideration of inequalities * |
|---|---|---|
| Agriculture, forestry and livestock | Seo and Mendelsohn (2008). Seo and others (2009). Economic choices of livestock owners to maintain production in the face of climate change in African countries. Econometric analysis. | Different farm types without analysis of inequalities. |
| | Butt and others (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 and others (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 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 | Nichols and Tol (2006). Coastal Regions at a global scale. Simulated adaptation options for coastal regions at the global scale (i.e., construction of seawalls and levees, beach nourishment and migration). | No. |
| | Neumann (2009). Risks of sea level rise for a portion of the coastal United States. Simulated adaptation options, including seawalls, bulkheads, elevation of structures, beach nourishment and strategic retreat. | No |
| | Purvis et al (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 diarrheal diseases, malnutrition, and malaria, downscaled for analysis in Indonesia and South Africa. | Inequality is not the central theme but the analysis of diarrheal diseases puts 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 and others (2009). Adaptation strategies compared to 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 and others (2011). Impacts of climate change trends on Brazil's economy. Socio-economic 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: Author's adaptation 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.

## Appendix 2: Approach to integrated climate change assessments

A number of tools are used in climate change assessments and the necessity of integrating them, generally in "top-down fashion", has been widely recognised. The cascade of analytical steps is represented in the flow chart below. Representative Concentration Pathways (RCPs) are used from the beginning to represent greenhouse gas (GHG) emissions and concentration pathways for the world, under different levels of mitigation. RPCs are used in analyses with global climate models, also known as Global Circulation Models (GCMs).




GCMs are numerical climate models that apply known physical, chemical and biological principles to simulate the interaction of the atmosphere, oceans, land surface, snow, ice and permafrost in determining the earth's climate. They describe climate changes over relatively large spatial and temporal scales under the RCPs scenarios: for example, in temperature, a variable that is relatively consistent over large spatial scales, and in precipitation, a variable influenced by smaller scale topographical features and cloud formations (McClusky and Qaddami, 2011). GCMs simulate a common set of scenarios where GHG emissions evolve according to their key drivers (population, energy technology, land use, and so on) and describe broad storylines of alternative, stylized future climate paths under these scenarios.

These scenarios provide information that is "downscaled" for deploying new scenarios, using global biophysical models. These new scenarios help understand how projections in temperature or precipitation, under given GHG emission and concentration assumptions, may affect a particular area or sector within an ecosystem, be it this land, energy, water, or others. The ultimate purpose is to assess the biophysical impacts of changes in climate to arrive at some sort of socio-economic evaluation.

The socio-economic evaluation is carried out adding two additional components. Firstly, there needs to be a global economic model through which the biophysical impacts of climate change are channelled and simulated to quantify economic impacts. Global economic models that are well integrated with biophysical models are generally known as Integrated Assessment Models (IAMs). These models represent the complex cause-effect relationship between biophysical processes that can be climate-driven and economic growth. Some integrated assessments also interface with different information systems (e.g. geographic information systems, including remote-sensing and global positioning systems), which provide powerful, process-visual, and spatially implicit decision-support systems (Mimura and others, 2014).

Secondly, so-called Shared Socioeconomic Pathways (SSPs) proposed by Kriegler et al. (2012) are being used to add socio-economic details. SSPs include three elements: storylines, which are descriptions of the state of the world; quantitative variables from the IAMs such as climate paths, population, gross domestic product (GDP), technology availability; and other variables, not included in the IAMs, such as ecosystem productivity and sensitivity or governance index (Burkett and others, 2014).The RCP scenarios presenting both GHGs emissions and concentration pathways generally correspond with the SSPs scenarios.

Altogether, global climate, biophysical and socio-economic scenarios are often downscaled to assess impacts, vulnerabilities and policy options at lower geographical levels. In this case, additional biophysical and economic models for a country, a region or a sector (or for all three levels) are deployed. Downscaling information from global models and scenarios could be through national models or directly through regional ones. In some cases, scenario results may even be scaled up if what happens at the sectoral level is expected to affect biophysical or socio-economic systems at the regional and national levels (Antle and Valdivia, 2016).

# Appendix 3: Assessment of climate shocks for Plurinational State of Bolivia[16]

UN-DESA works with the Economic Policy Unit (UDAPE) of the Ministry of Development Planning and other government entities in the Plurinational State of Bolivia to build capacity in the use of economy-wide modelling tools to inform policy makers.[17] Socio-economic impacts of hypothetical climate shocks and policy responses have been analysed as part of this collaborative effort, aiming at capacity building rather than at evaluating any policy of the Government.

The analysis is based on an economy-wide model whose baseline scenario projects, until 2080, a continuation of the economy’s trajectory and policies seen during 2010-2016. Scenarios of climate shocks, with and without policy responses, are compared with the baseline scenario for analytical purposes. The magnitude of the shocks represents the upper bound of a range of possible impacts determined from existing studies. The shocks are as follows:

- labour productivity gradually decreases in all sectors of the economy as of 2017 until falling by 10 per cent by 2080, as a result of rising temperatures;
- 50 per cent of public infrastructure is destroyed in 2020, as a result of an extreme weather event; and,
- the price of food rises gradually as of 2017 until it is 70 per cent higher by 2080, as a result of climate change.

One of the policies under analysis is an increase in government health spending by 15 per cent seeking to boost labour productivity to offset the initial productivity shock (the first shock above). A second policy is considered by combining the infrastructure shock (the second shock above) with increased government investment that fully recovers the lost infrastructure in 2024. Each policy is assessed separately, assuming that one of the following sources at the time finances its implementation: foreign borrowing, domestic borrowing or direct taxation. This gives a total of six policy scenarios under analysis—and a total of 9 scenarios altogether.

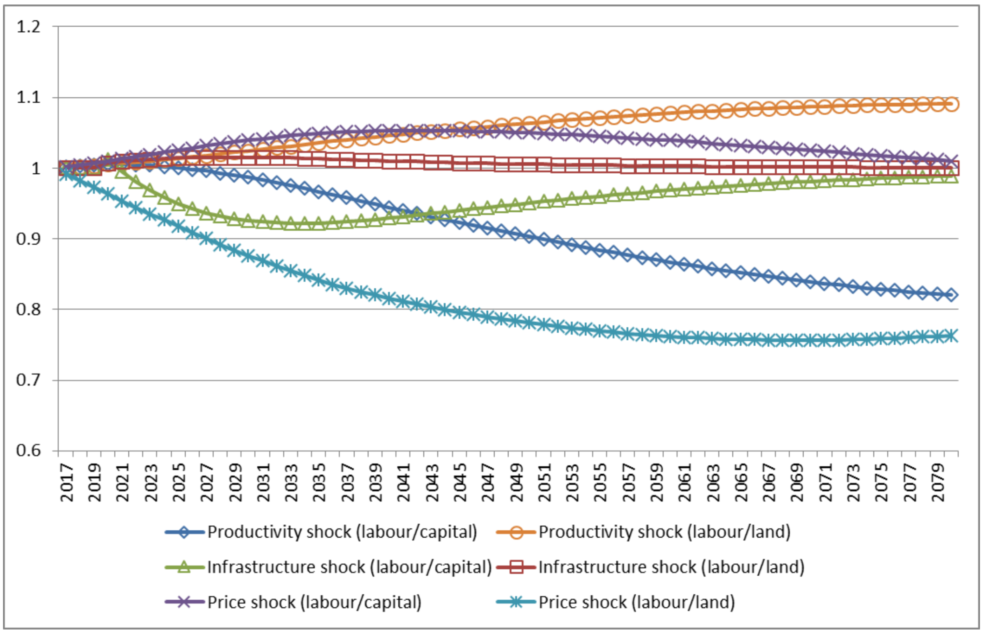
### Economy-wide impacts

In the three initial scenarios (without policy), the climate shocks reduce gross domestic output (GDP). There are important changes in factor income distribution as a result (figure A.3.1). The negative impacts of a decrease in labour productivity are particularly seen through effects in the labour market: wages and employment decrease. The average wage relative to the average capital return decreases by 18 per cent in 2080. On the other hand, capital becomes relatively scarcer after the abrupt “infrastructure shock” is simulated, which

[16] Martin Cicowiez contributed inputs for the elaboration of this appendix
[17] This collaborative effort between UN-DESA and the Government of the Plurinational State of Bolivia is coordinated by the author of this paper.

transitorily affects the distribution of factor incomes with wage earners losing out more compared with capital owners—until the economy converges to the pre-shock situation.

**Figure A.3.1 Plurinational State of Bolivia: labour wage/capital return and labour wage/land rent ratios, under climate shock scenarios (deviation from baseline scenario values)**




Source: Author’s estimates.

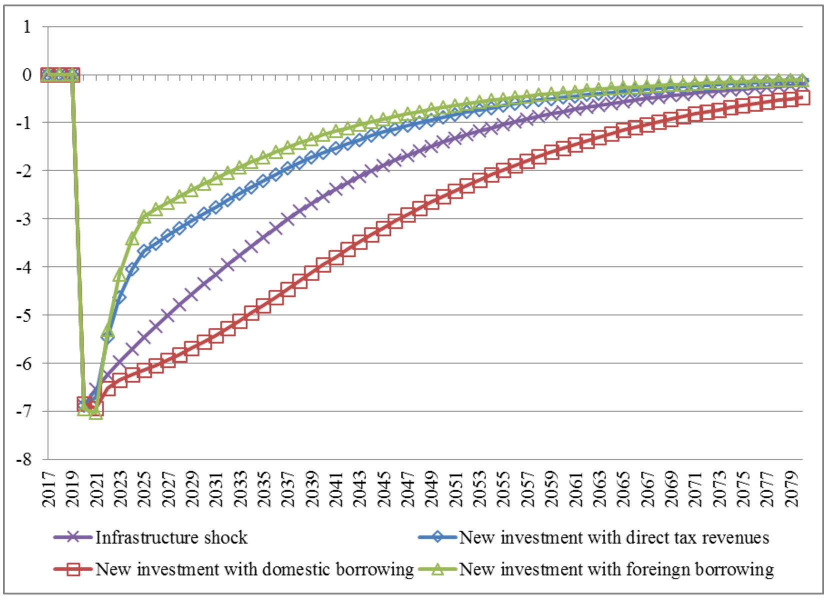
The “food price shock” is different. Bolivia is a net exporter of agriculture and food products and the sectors that produce them grow and gain as a result of increasing food prices. Interestingly, because the growing sectors are relatively labour intensive, the shock results in a reduction of unemployment. In terms of income distribution, the wage-to-land return ratio falls and this is not observed in the other scenarios. The labour wage/capital rent ratio tends to improve, first rapidly, then less rapidly as it converges to the pre-shock situation. Unskilled non-salaried workers are most benefited by the increase in the world price of food because of the large presence of unskilled small farmers and self-employed workers in food production.

**Macroeconomic impacts of policy responses**

More public investment (in the policy scenarios) helps to cope with the climate-related shocks, but the final effect on GDP growth depends on the financing source of the new investment. Consider for simplicity only the case of new public investment in infrastructure. Output recovers most—albeit not fully—when foreign borrowing finances the investment (figure A.3.2). The inflow of foreign resources however gives rise to a slower export growth and faster import growth in this case, inducing an appreciation of the real exchange rate.

Thus, there are winners (non-tradable sectors) and losers (tradable sectors). Overall foreign financing allows increasing household consumption and GDP at a higher growth rate. Alternatively, if the financing comes from domestic direct taxation, there is less disposable income, such that consumption is depressed as well as savings to some extent. In the case of domestic borrowing, there is an important reduction in domestic absorption that exacerbates the economic impacts of the climate shocks. Although public investment replaces private investment, the latter tends to be crowded out in detriment to GDP growth which is an unintended consequence of the simulated policy.

**Figure A.3.2 Bolivia: Real GDP under infrastructure shock scenarios without and with new investment and financing (percentage deviation from baseline scenario)**



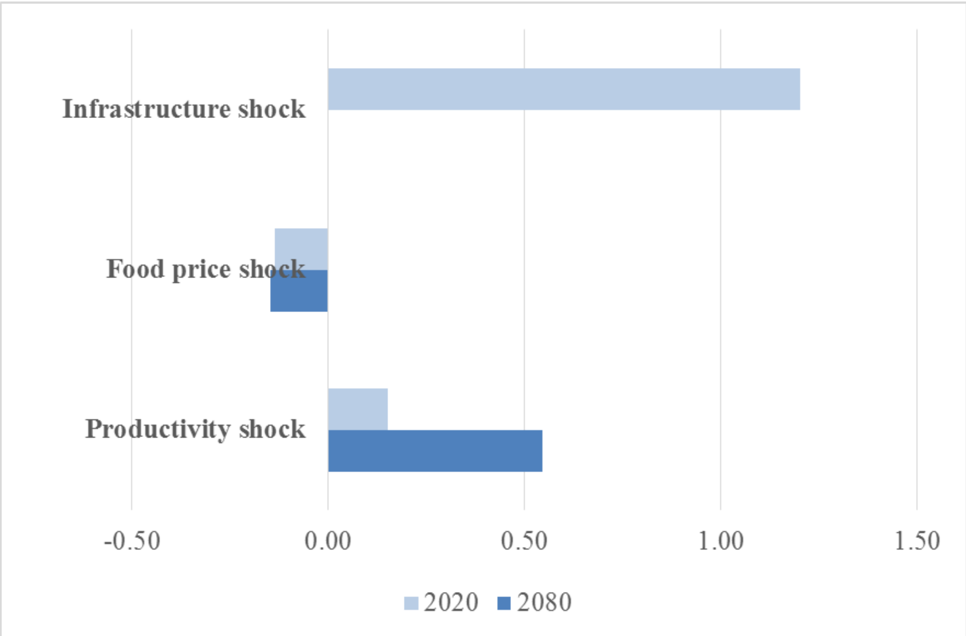

Source: Author's estimates.

There are additional considerations. Domestic borrowing or foreign borrowing may lead to debt sustainability issues, or it is unrealistic to believe that tax revenues can suddenly grow by a few points of GDP—all of which need to be part of a rigorous assessment in practice. Indeed, borrowing or tax revenue are over time a few points of GDP above the baseline scenario (not shown here). In practice, of course, policy makers have to assess scenarios where policies are financed using a mix of options, depending on fiscal and debt sustainability concerns.

**Effects on poverty**

Results from the economy-wide model were imposed on the 2013 household survey carried out by the National Statistical Institute of Bolivia (Plurinational State of), in order to run microsimulations and arrive at estimates of changes in poverty and income distribution for the different scenarios. Income poverty rises as labour wages are hit adversely as a result of the productivity and infrastructure shocks, both in absolute terms and in relative terms vis-à-vis capital (vis-à-vis other factors such as land the changes are smaller) (figure A.3.3). Because the infrastructure shock was introduced abruptly, poverty increases much more in 2020 compared with the productivity shock. The impacts on income distribution at the household level, as measured by the Gini coefficient (not shown here), were found to be small because the shocks, as designed above, affect all sectors of the economy. The results are different in the case of the food price shock. Because unskilled non-salaried workers are most benefited by the food price hike, the poverty headcount ratio (figure A.3.3) as well as income inequality (not shown here) record a modest reduction. In the policy scenarios, the adverse effects of the productivity and infrastructure shocks on poverty are ameliorated (not shown here).

**Figure A.3.3 Bolivia: Poverty rate (US$ 2 per day) under climate shock scenarios (deviation from baseline scenario values)**

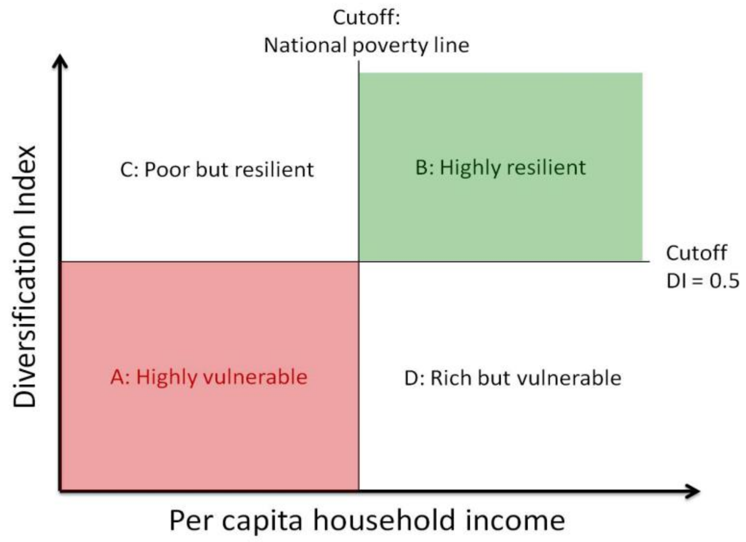



Source: Author's estimates.

## Appendix 4: Determinants of vulnerability and resilience: a household survey-based analysis[18]

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.4.1).

**Figure A.4.1: 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 $i$th income source. The value of the index is 0 when there is complete specialization (100 per

[18] Lykke Andersen contributed inputs for the elaboration of this appendix.

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 is 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.4.1). 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 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 and resilience are remittances and a public sector job, which both 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.

**Table A.4.1: 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 obs.* | *8848* | *8848* |
| $R^2$ | *0.148* | *0.1747* |

*Source*: Andersen and Cardona (2013).
*Note*: The numbers in parentheses are *z*-values.

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