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Climate Change and
Sustainability Division

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This study includes results of three studies from Brazil, Mexico and Bolivia developed under the research initiative “Assessing local vulnerability to climate change in Latin America and the Caribbean” coordinated by Carlos Ludena and Leonardo Sanchez-Aragon of the Climate Change and Sustainability Division (INE/CCS) of the Inter-American Development Bank (IDB).

The research initiative was developed in close collaboration with Sebastian Miller from the Research Department (RES/RES), Sebastian Corderi from the Environment, Rural Development and Natural Disasters Division (INE/RND) and Fernando Miralles from the Water and Sanitation Division (INE/WSA), and the sector specialists from those divisions in charge of the IDB projects analyzed under this research.

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Vulnerability Indicators of Adaptation to Climate Change and Policy Implications for Investment Projects

Relevant and appropriate indicators for vulnerability at both the local levels are significant for effective adaptation to climate change. The paper reviews the literature of these indicators, and explores this issue using a selected sample of development projects from the Inter-American Development Bank (IDB) to assess the measurement of vulnerability. We find the importance of assessing vulnerability based on local indicators reflecting the characteristics of different sectors. The results of analyzing the IDB projects case studies suggest that projects should be designed from project inception to include more relevant indicators of measuring exposure and sensitivity besides adaptive capacity, depending on the attributes of projects. We show that relevant vulnerability indicators can be developed for projects based on existing information.

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1. Introduction

In the recent past, vulnerability measures have been used extensively in interdisciplinary research to explain the degree to which a socio-economic and environmental systems suffers from climate change. The popular measure of vulnerability at the earlier stage of theoretical development has been based upon the scientific simulation of economic loss from climate impacts on bio-physical conditions of the environment. Those simulation results depend on the available technology and resources of the communities and organizations affected by an adverse change.

From the socio-economic perspective, however, it is a result of how sensitive a system is to environmental hazards, and how effectively the affected people can act to reduce the detrimental effect of the structural change in climate. The so-called common-pool resources and public goods at multiple scales are required to cope with climate change. Depending on the attributes of the affected communities and sectors and magnitude of climate impact, a diverse set of institutional arrangements at both the local and sector level is expected to emerge. However not all of them are guaranteed to succeed to mitigate the climate impacts.

The potential of a system to adjust to external disturbances and thereby limit risk is usually referred to as adaptive capacity (Smit et al. 1999; Smit and Skinner, 2002; IPCC, 2014 and 2007). Adaptations can be undertaken by individuals, groups or organizations on multiple levels as a response, either in a coordinated manner as a collective action or on an individual basis in an uncoordinated way. The government can either play an active role in the adjustment process or leave the major function of adaptation to private initiatives. The empirical evidence suggests that relative success differs on a case by case basis depending on geographical location, communal attributes, and industrial sectors. Earlier studies on the performance of diverse institutional arrangements in creating and maintaining common-pool resources in coping with external changes in the biophysical environment show that there exists no universally efficient rule of governance that can be applied to vulnerability analysis (Ostrom, 2005, 2009, 2010).

Vulnerability measures thus emphasize the local level case or context. Field research may reveal that neighboring communities respond differentially to climate impact depending on their information and abilities to develop and implement appropriate strategies. For example, farmers who ascertain structural changes in rainfall and soil quality would likely to mitigate external impacts and have to build infrastructure to preserve the biophysical environment as much as possible. They need to collect information on profitability of substitute agricultural products and technology. Due to the lack of access to formal capital markets and technical know-how to build necessary facilities and invest in new crops, farmers may choose to behave in a collective manner and need institutional arrangements to support their actions. It requires a detailed contextual understanding of the relevant systems and how they are impacted by various structural changes.

What makes the measure of vulnerability more difficult is that economic consequences of communal response that we observe through field studies also depend on the socio-economic structural changes such as globalization and financial crisis which take place independently with long-run climate changes. For example, import prices of food and raw materials as well as job market conditions, both at home and abroad certainly affect the opportunity set of local farmers, and influence their response. Most importantly, it requires a careful empirical analysis to separate the contribution of communal or adaptive effort from other conditions that take place in conjunction with these climate impacts. Research in this vein includes double-impact or multiple-impact studies (O'Brien and Leichenko 2000). Most importantly however, a careful design of econometric analysis is required to examine the relationship among the relevant variables.

To investigate causality between climate changes and socio-economic consequence, we need to identify which actors will be impacted, what their roles, positions, information and resources are with respect to adaptation (Smit and Skinner 2002), and to characterize a way to systematize and organize the complex body of data gathered. Any methodology to that end would require understanding actors' own perceptions of the context of change at the sector-specific local level and how they perceive and rank different risks that results from climate change.

Based upon the assessment of actors' perception and imperfect information on new technology and outside resources, we can evaluate the pattern of ownership in building new infrastructure, the size of business operations, general constraints over time including governance structure such as legal regulations. The complexity of the task may explain why methodologies for vulnerability assessment have been slow to develop (Tol et al. 1998; Fankhauser et al. 1999).

The paper applies such a context-sensitive approach to vulnerability analysis and measurement and investigates vulnerability assessment at the local-sector level such as agriculture, coastal areas, water, forestry and health. The paper explores a possibility to devise indicators that can aggregate and convey sector-specific information at the local level. Those indicators then become components of the sectoral index that can be applied systematically at the local level. In that context, the paper analyzes a sample of selected Inter-American Development Bank (IDB) development projects that may reduce vulnerability and/or build adaptive capacity in the agriculture, forest, water and coastal management sectors.

The paper is organized as follows. In section 2, the paper carefully reviews and conceptualizes vulnerability to climate change. The paper conducts literature surveys on vulnerability indicators (global versus local) in section 3, particularly focusing on the local vulnerability indicators by sector. In section 4, the paper analyzes the selected IDB's development projects. Finally, in section 5 it concludes and suggests policy implications for project development.

2. Conceptualization of vulnerability

The term of "vulnerability" has varied widely according to scholars and research domains as well as time. Therefore, it is generally accepted that a single definition of vulnerability satisfying all assessment contexts does not exist (Füssel, 2007; Kasperson, 2005). Füssel (2007) also points out that the existence of various definitions of vulnerability can bring about a number of problems especially in research on climate change areas. There have been a bunch of studies dealing with the conceptualization of vulnerability to climate change (Adger, 1999; Moss et al., 2001; O'brien et al., 2004, Füssel, 2007; Barr et al., 2010).

Meanwhile, the Intergovernmental Panel on Climate Change (IPCC, 2001)[1] defines the vulnerability in climate change as "the extent to which a natural or social system is susceptible to sustaining damage from climate change." In this occasion, we can know that the category of vulnerability is limited to exposure and sensitivity. However, the IPCC (2007) expanded to adaptive capacity by defining the concept as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes."

Our paper adopts these three components as key factors in determining a system's vulnerability to climate change and in providing useful information for assessing and reducing climatic threats (Figure 2).

[1] The IPCC, established in 1988 by the World Meteorological Organization and the United Nations Environment program, reviews and evaluates worldwide scientific, technical and socio-economic information on climate change. This organization is known as the most credible existing sources of climate change information.

Figure 2. Factors determining a System's Vulnerability to Climate Change

EXPOSURE

Climate exposure indicators may include bio-physical factors such as temperature rise, heavy rain, drought, and sea level rise. The IPCC predicts that the impact of global warming will continue as the probability of severe heat waves, heavy rain, drought, tropical depression and sea level rise increases over time (Parry et al. 2005).

SENSITIVITY

The degree of a system's sensitivity to climatic hazards depends not only on geographic conditions but also socio-economic factors such as population and infrastructure. Indicators of sensitivity can encompass geographical conditions, land use, demographic characteristics, and industrial structure such as dependency on agriculture and extent of industrial diversification.

ADAPTIVE CAPACITY

Adaptive capacity describes the ability of a system to cope with climatic extremes. Generally speaking, adaptive capacity to climate change depends on physical resources, access to technology and information, varieties of infrastructure, institutional capability, and the distribution of resources. Indicators for adaptive capacity compose economic capability, physical infrastructure, social capital and institutional capacity, etc. Economic capability represents the economic resources available to reduce climate change vulnerability. It includes human resources and technological alternatives (Yohe and Tol, 2002).

Physical infrastructure describes the hardware available to enhance adaptive capacity, while indicators of social capital include social network of individual know-how and mutual trust to cope with climate impact. Institutional capability is represented by the political leadership and governance structure, disaster prevention systems, and climate change policy. For example, systems of local food supply and distribution, early warning systems, accessibility to relevant information, and availability of crisis management programs and policy (McCarthy et al., 2001) are part of adaptive capacity. Some authors explain that adaptive capacity at the local level involves accessibility to political power, specific beliefs and customs (Cutter et al., 2000).

3. Local vulnerability indicators at the sectoral level

As noted in Ludena and Yoon (2015), the development of national-scale indices for illustrating countries' vulnerability to climate change fall short, as adaptation is dealt at the local level. Global vulnerability indices have been criticized for various reasons such as aggregation of country-specific characteristics over time, reliability of the data and sensitivity of the choice of proxy variables, etc. For example, Eakin and Luers (2006) question the validity of national level vulnerability noting data quality, indicators used, assumptions and mathematics used for aggregating variables. Eriksen and Kelly (2007) conclude that there is there is little consensus on country rankings of vulnerability through reviewing five national-level indices of social vulnerability to climate change from the related literature. Füssel (2009, 2010) also points out that the global vulnerability indices aggregated by heterogeneous indicators which have conceptual, methodological and empirical flaws, concluding these indices are not sufficient for a benchmark criterion of international climate policy.

Most adaptive responses will be made at the local level by resource managers, municipal planners, and individuals. Local vulnerability assessment is based on the qualitative analysis of climate change impacts using a matrix of the participatory process. The so called ‘bottom-up’ approach has been commonly used for this type of local vulnerability assessment. Through reviews of the related studies, we find the following characteristics (scale, dynamics and diversity) that local vulnerability measure should take into account in order to convey information on diverse natural environments and heterogeneous socio-economic structure at multiple scales which lacks in aggregate vulnerability indices.

- *Scale.* Many recent vulnerability studies argue that the vulnerability assessment depends critically on the scale of analysis. The assessment at the local scale becomes critically important not only because of the bio-physical environmental differences of locations, but also because of the socio-economic contextual differences at the local level. For example, even if we attempt to measure vulnerability to climate hazard (i.e. flood), heterogeneity of locations even within a country or specific region is often responsible for differential response (i.e. coping capability) to that hazard. Furthermore, within a country or region, heterogeneity of socio-economic contexts such as institutions, population, social network and culture, may affect the local vulnerability to climate change (Adger, 1999; Adger et al. 2004; Carina and Keskitalo, 2008; Engle and Lemos, 2010).
- *Dynamics.* The vulnerability assessment requires a dynamic point of view (Liu et al., 2008; Eriksen and Silva, 2009; Frank et al., 2011). However, global-based studies on vulnerability to climate change using static proxy variables such as annual GDP may ignore the dynamically changing coping capability at the local scale over a period of time. Individual perception and accumulated knowledge of climate change that evolves over time results from learning through the past experiences of households response to climate change, their attitudes, values, culture and norms. In fact, it has been shown from the number of behavioral studies that individual awareness is one of the critical factors that determine the degree of local vulnerability. For empirical studies, it is important to characterize individual awareness in a continuously changing environment in an adverse manner.
- *Diversity.* By focusing on micro level unit of analysis such as household or community ecosystem, it becomes feasible to capture the diversity of the natural environment of

communities and their socio economic heterogeneity (Adger et al., 2005; Schroter et al., 2005; Flint and Luloff, 2005; Acosta-Michlik and Espaldon, 2008).

Meanwhile, it is necessary for measuring the local vulnerability by different sectors in order to create local vulnerability measures that consider above four characteristics, In fact, through various country-specific case studies and projects, we find that sector specific or multiple sector local vulnerability and adaptation measure have been identified at different locations. Practitioners are in great need of sectoral indices that can be applied systematically at the local level. The most commonly examined sectors used by local vulnerability assessment studies include agriculture, disasters, health, coastal zones, water and food (Füssel, 2009; Barr et al., 2010). In particular, we focus our case study of local vulnerability indicators on the four specific sectors such as agriculture, coastal zones, water resources and forest. Although we find that some indicators which have been identified in local case studies overlap across sectors, many indicators turned out to be sector-specific, distinguishable and exclusive.

3.1 Agriculture

Most of the case studies that adopt the bottom-up approach confine their analysis to selected agrarian communities to examine the vulnerability of agriculture to climate change. Table 1 presents a summary of local vulnerability indicators in agricultural sectors, given the three dimensions of exposure, sensitivity and adaptive capacity that are described in the following paragraphs.

Exposure. The agricultural sector is exposed to climate related hazards from the bio-physical domain.[2] Major hazards include precipitation variability, seasonal temperature change and extreme events such as drought, flood, sea level rise and water intrusion. The exposure measures generally depend on the above mentioned climate driven hazards.

Sensitivity. Studies on local agricultural sectors focus on agrarian communities consisted of individual households belonging to different age cohorts at varying locations. Mimura (1999) examined vulnerability of the farmers in low laying coastal areas who are vulnerable to salt water intrusion and destruction of farm land. Hay and Mimura (2006) focused on sensitive mangrove habitats and wet tropic in the small agrarian communities. Some studies emphasize relatively sensitive population (e.g. seniors) in the agrarian communities (Gay et

[2] See Kelkar et al. (2008), Ford (2009), Deressa et al. (2009), Krishnamurthy et al. (2011), and Rawlani and Sovacool (2011) for the bio-physical determinants of vulnerability.

al., 2006; Acosta-Michlik and Espaldon, 2008; Knutsson and Ostwald, 2006; Ben Mohamed, 2011).

Adaptive capacity. The bottom-up case studies in agrarian communities are usually interested in assessing vulnerability by examining how socio-economic institutions are managed to curb the negative impact of climate change, once bio-physical domain is given. The following aspects of local analysis deserve attention.

Local environmental knowledge for farmers provide observations and interpretations at smaller geographical scales, where systematic meteorological records are often scarce and predictions of climate change and its impacts are most uncertain (Marin, 2010). Community members are likely to prefer and be motivated to carry out particular strategies that align with community values, attitudes and norms. Perceptions can also influence these preferences and motivations which may lead to building community level adaptive capacity.

Household case-study survey results demonstrate that farmers' individual perceptions affect their coping strategies and consequences. In particular, information or knowledge on climate change and its impact to agriculture are found to be one of the significant variables on local vulnerability. A number of studies recognize information as an important determinant that formulates adaptive capacity at the local level. For example, the local vulnerability assessment based on a semi-structured survey identified that awareness and level of knowledge about climate change and its impact on agriculture as one of the key factors. (O' Brien et al., 2004; Knutsson and Ostwald., 2006; Hay and Mimura, 2006; Parkins and Mackendrick, 2007; Tschakert, 2007; Deressa et al., 2009; Few and Tran, 2010; Marin, 2010).

Dependency of income in agriculture is an important aspect of vulnerability and is caused by reliance on a narrow range of limited resources. Resource dependency and its effects can be captured by reliance on climate dependent resources, variability in such income sources, and migration and other social variables associated with stability and resilience of the community (Adger, 1999). One of the most common ways to measure local coping strategies to mitigate resource dependency found in local vulnerability case studies are diversification and/or specialization of occupation or crops. (Adger, 1999; Bradshaw et al., 2004; Alcamo et al., 2007; Eakin et al. 2007; Acosta-Michlik and Espaldon, 2008; Kelkar et al., 2008; Kuruppu, 2009; Liu et al., 2008; Hahn et al. , 2009; Deressa et al., 2009; Armah et al.,2010).

Diversification of income sources may be a good strategy to reduce resource dependency and vulnerability of individuals at the household level. However, depending on the circumstances, diversification can also result in increased vulnerability. For example, Liu et al. (2008) suggest that specialization, considered another important adaptation strategy besides diversification, is the key to the success of improving the well-being of farmers. They pointed out that a specialty economy depends on the local leaders and entrepreneurial innovations for promoting the produce outside of the village.

Several case studies argue that informal collective action and the network among rural farmers are significant variables that affect the local vulnerability level (Adger 1999; Mimura 1999; Folke et al., 2002; Knutsson and Ostwald, 2006; Osbahr et al., 2008; Toni and Holanda, 2008; Acosta-Michlik and Espaldon, 2008; Deressa et al., 2009; Few and Tran, 2010**;** Armah et al., 2010; Ben Mohamed, 2011). For example, Folke et al. (2002) pointed out that it is possible to see how livelihood resilience can be eroded or enhanced through identifying different levels of management (e.g. community-based organizations, boundary and bridging organizations or external policy interventions). Acosta-Michlik and Espaldon (2008) used farmers' cooperation as a proxy variable for a network indicator. Toni and Holanda (2008) argued that farmers using common pastureland have a more diversified system and invest more in a small animal husbandry adapted to the dry environment.

O'Brien et al. (2004), and Eriksen and Silva (2009) argued that economic variables responsible for adding volatility of household income can increase risks in the subsistence-based economies. Microeconomic wealth indicators such as household income, expenditures and non-farm income as well as structural variables that affect the household income turn out to be significant variables that affect local vulnerability.

Few and Tran (2010) investigates how household income itself combined with differential entitlements to resources shape patterns of vulnerability to climate extremes. Acosta-Michlik and Espaldon (2008) also include several indicators of economic activities to measure local vulnerability. For example, they include level of household income as well as the non-farm source of income.

Almost all case studies have identified variability of farm and non-farm income as one of the important determinants of local vulnerability. In addition to the monetary measure of farm and off-farm income, Crabbe and Robin (2006) finds that land use characteristic (i.e. crop characteristics) and economic activities (i.e. income from major crops and its proportion to regional income) are a critical factor of local vulnerability.

Credit to borrow money from the bank also is also referred in the several case studies as it directly relates to household income and management of potential climate driven risks in agriculture (Acosta-Michlik and Espaldon, 2008, Deressa et al., 2009).

Fixed assets of farmers such as physical capital are identified as significant economic components that form local vulnerability since the value of the physical capital fluctuates over time. Fixed assets may include soil quality (Kelkar et al., 2008), agricultural machineries, agricultural infrastructure such as roads (Knutsson, and Ostwald, 2006, Eriksen and Silva, 2009). Some studies find that irrigation facility is one of the important assets of farmers that reduce vulnerability (Bradshaw et al., 2004; Liu et al., 2008; Alcamo et al., 2007; Knutsson and Ostwald, 2006; Kelkar et al.,2008; Deressa et al., 2009).

Social identity is also identified as a crucial factor that influences both magnitude of adverse impacts from climate change and response capacity (Frank et al., 2011). Information on social identity of decision maker is contained in socio demographic characteristics such as age and social status inherited from their parents. Individuals' perceptions of risk of information and self-efficacy often reflect how they see themselves in terms of group membership (Gecas, 1989; Huddy, 2001; Smith, 2007). The way that farmers acknowledge scientists and their knowledge is likely to affect farmers' use of scientific information in making agribusiness decisions.

Frank et al. (2011) explores the relationship of social identity, perception of the validity of information sources, and adaptive motivation in detail through scenario questions with the 17 farmers who participated in the in-depth interviews. Their survey data and qualitative interviews were used to construct farmers' identities through diverse and overlapping associations, including geographic proximity and place-based ties, occupation, access to mass media, and participation in cooperatives.

Experiences and identity appear to go hand-in-hand. In fact, a number of case studies have included the level of education as a proxy measure of social identity that gauges household's or communities' coping capacity (O'Brien et al., 2004; Hay and Mimura, 2006; Knutsson and Ostwald, 2006; Parkins and Mackendrick, 2007; Tschakert, 2007; Acosta-Michlik and Espaldon, 2008; Kuruppu, 2009; Deressa et al., 2009; Few and Tran, 2010).

Table 1. Summary of possible local vulnerability indicators in agricultural sectors

Components	Possible indicators	
Exposure	Precipitation variability Temperature variability Extreme events (e.g. drought, flood, cyclone)	
Sensitivity	Costal farm	Salt water intrusion and destruction of farm land (low laying farm areas; coastal spring destruction and diseases)
	Small rural agrarian communities	Mangrove habitats/wet tropic
	Population	Vulnerable age of population
Adaptive capacity	Economic	Dependency on rain-fed agriculture or resources Income, non-Ag income Nominal income, real wage, real expenditure, medical expenditure, disposable income Domestic price and world price (or openness) Physical assets (i.e. animals, vehicles, machines, house and land) Diversification of occupation and crops Immigration option
	Social	Community network Collective action (e.g. religion based activities observed from marriage and funerals)
	Infrastructure	Buildings and road Access to water Irrigation system Public health Transportation system
	Individual knowledge	Awareness of clime driven risk based on past threats Level of education /cost of education
	Institutional	Government social interventions (education policy, credit for low income farmers, immigration policy)

Source: Based on Ludena and Yoon (2015).

3.2 Coastal zones

Table 2 presents a summary of local vulnerability indicators in agricultural sectors, given the three dimensions of exposure, sensitivity and adaptive capacity that are described in the following paragraphs.

Exposure. Coastal zones are also influenced by a geodynamical structure and are highly exposed to threats from adverse climate impacts and socioeconomic activities (Klein and Nicholls 1999; Furlan et al., 2011). Continual flooding, coastal erosion, and loss of livelihood of coastal communities testify to the pressure and vulnerability faced by this unstable environment (McFadden and Green, 2007).

Mimura (1999) points out that the primary impacts of sea level rise take the form of inundation, coastal flooding, soil erosion and saltwater intrusion into rivers and underground aquifers and changes in sediments deposition patterns. Many case studies describe how the projected sea-level rise and climate change due to human emissions of greenhouse gas would affect a particular area in the selected region (e.g. Chemane et al., 1997; Zeidler, 1997; Dolan and Walker, 2006; Hay and Mimura, 2006; Harvey and Woodroffe, 2008; Hwang et al., 2009; Yoo et al., 2011).

Some case studies focus on specific climate driven extreme events such as hurricane, typhoon, cyclones and tsunami, and their impacts on the eco-system and urban or rural dwellings. For example, Lebel et al. (2011) points out that coastal floods and tsunami is one of six main flood regimes that are affected by climate change. They identify that coastal farming and fisher communities, tourism dependent communities and small fisher coastal communities and urban dwellings in low-lying areas are vulnerable to the coastal flood and tsunami.

Sensitivity. The local coastal communities and vulnerable population are commonly referred sensitive units of analysis. However, coastal forest (e.g. Hughes, 2011; Hay and Mimura, 2006), coastal urban cities (e.g. Zeidler, 1997; Yoo et al., 2011) and coastal tourism (e.g. Nicholls and Klein 2005; Manuel-Navarrete et al., 2011) are also regarded as sensitive units.

A common theme that emerges out of a number of case studies that focus on coastal areas is how to assess climate impact and vulnerability which helps coastal management (Nicholls and Klein, 2005). Given the IPCC (2007) report that the average sea level is projected to rise by 0.18 m to 0.59 m by the end of the 21st century, urban areas near the coast are also vulnerable to the sea level rise. Vulnerability of coastal cities has been the subject of recent local vulnerability studies. For example, Hwang et al. (2009) reports economic damage from the sea level rise in Busan, the second largest city in Korea.

For coastal areas, what matters is not the global-mean sea level but the relative sea level of the local area with features of regional sea-level variations and vertical movements of the land (Nicholls and Klein 2005). Several studies argue the importance of relative location in coastal areas in assessing the coastal sector vulnerability. For example, Zeidler (1997) examined four geologically different “impact regions” in Poland, based on sea level rise scenarios and identified the most vulnerable region. Adger (1999) examined social vulnerability through resource dependency and poverty. He considered proximity to the coast as one of indices of vulnerability. Mimura (1999) examined the location of population in the low-laying areas that decide how many people will be at risk due to sea level rise.[3] Sensitivities to heat waves and heavy rainstorm are quantified using the expert opinions from survey and information on land use classification. Dolan and Walker (2006) introduce a case study of assessment of climate change vulnerabilities in Canada’s most sensitive coast, Graham Island. Although they point out the significance of incorporating socioeconomic capacity to cope with climate change with biophysical impacts, their assessment is not based on quantitative results, but based on a qualitative statement emphasizing sensitive landscape, extreme climate variability and the economic dependence on variables and restricted natural resources. Harvey and Woodroffe (2008) also summarize several efforts to evaluate coastal vulnerabilities in Australia and criticized that there is little consistency or uniformity in the way in which Australian coast to the impacts of climate change.

Coastal tourism has also been noted as one of the main topic from many local vulnerability studies in developed countries. (e.g. Nicholls and Klein, 2005; Manuel-Navarrete et al., 2011). Manuel-Navarrete et al. (2011) examine vulnerability of the tourism sector in Mexico, Cancun to increasing frequency of hurricanes. It is reported that despite robust infrastructure and the inflow of foreign capital which has increased coping capacity of Mexican Caribbean, degraded eco-system and undemocratic governance in the region raised overall vulnerability.

Adaptive capacity. Adaptive capacity indicators that have been identified and related to diversity of income sources in coastal sectors share in common with adaptive indicators in the agricultural sectors. For example, income composition of coastal communities that depend on management of coastal resources such as fisheries, agriculture, tourism and forest affects social welfare of inhabitants (Chemane et al., 1997). Adaptive capacity certainly depends on variability in income. Some measures, however, distinguish adaptive capacity of coastal vulnerability from the other sectors. These include infrastructure such as

[3] See Yoo et al (2011).

buildings and roads in coastal areas (i.e. Krishnamurthy et al., 2011), drainage system (e.g. Rawlani and Sovacool, 2011) and natural barrier in coastal areas such as mangrove (e.g. Mimura, 1999; Hay and Mimura, 2006; Hughes 2011).

Table 2. Summary of local vulnerability indicators in coastal sectors

Component	Possible indicators	
Exposure	Coastal morphological processes (bank erosion, coastal flood, storm, wetland damage) Extreme events (e.g. tsunami , cyclones) Sea level rise Heavy rainstorm Heat wave	
Sensitivity	Costal location	Salt water intrusion and destruction of farm land or destruction of houses near the coast
	Coastal forest	Mangrove habitats Wet tropic
	Coastal ecosystem	Coral reefs
	Small fisher coastal communities	Fishery related issues such as decreasing productivities due to climate variability and increasing extreme events
	Coastal urban cities	Business and local economy that are based on coastal region
	Costal tourism	Hotels , resorts, etc.
	Population	Increasing vulnerable population (e.g. over 65)
Adaptive capacity	Economic	Dependency on agriculture or fisheries Composition of income Flexibility of occupation and migration
	Social	Coastal community network Collective action
	Infrastructure	Buildings and road in coastal areas Drainage system Health status (e.g. average time to health facility)
	Individual knowledge	Awareness based on past threats
	Institutional	Government social interventions
	Natural barrier	Coral reefs/ mangroves and sandy beaches

Source: Based on Ludena and Yoon (2015).

3.3 Water resources

Exposure. Impacts of climate change on water availability and quality, for example, is likely to threaten the sustainability and increase the risk for social and ecological systems. Temperature rise would accelerate the spring snowmelt and result in faster and earlier spring runoff. Mountainous areas with such runoff would be particularly vulnerable to increased flooding. In general, flood frequencies are most likely to increase in the higher latitudes (Frederick and Schwarz, 1999; Crabbe and Robin, 2006; Alcamo et al., 2007; Acosta-Michlik and Espaldon, 2008; Liu et al., 2008; Kelkar et al., 2008).

In addition, the water sector is exposed to extreme events such as drought and flood. According to the IPCC (1997) report, reduced precipitation can bring higher frequency and greater intensity of drought in some areas. Lal et al. (2011) points out that possible limitation on water supply by projected temperature increases in the region becomes more serious if the rain and snowfall in the spring months are reduced substantially. They also pointed out that as regional and seasonal precipitation patterns change and rainfall becomes more concentrated in heavy events, floods are also projected to be more frequent and intense.

Sensitivity. The water sector has been regarded as an extremely sensitive sector to climate change precipitation variability (Füssel, 2009). Also, as water quality and availability become increasingly stressed with climate change, the ability to absorb these stresses and cope with new realities and potential future disasters becomes critical (Engle and Lemos, 2010).

Impacts of climate change on water availability and quality, for example, are likely to threaten the sustainability and increase the risk for social and ecological systems. Furthermore, the probability of facing drought and flood remains non-negligible despite the sizeable investments to control flood waters and increase available supplies. Given the infrastructure of the community, climate change could alter both the frequency and magnitude of large floods.

Since agricultural products are most susceptible to short-term and prolonged water shortages, rural communities that highly depend on water resource for agriculture are common units of analysis in local vulnerability studies (Acosta-Michlik and Espaldon, 2008; Liu et al., 2008; Kelkar et al., 2008). Drought may result in reduced crop production, soil losses from dust storms, or higher water costs.

Biodiversity such as fish and trees may have suffered from the most severe impacts of this prolonged drought. Milly et al. (2008) suggest that the eastern part of U.S. will experience increased runoff, accompanied by declines in the west (e.g. Southwest region of U.S). This means that wet areas are projected to get wetter and dry areas drier, thus increasing the vulnerability of agricultural and forest-dependent communities whose livelihoods (or incomes) in many cases are sensitive to water availability.

Population growth in these arid and semi-arid regions could also stress water supplies. The impact is likely to become more severe for urban centers than rural counties. Farley et al. (2011) points out that vulnerability to climate change in the water sector may vary by location and the amount of water use. In addition, they point out that the demographic growth exacerbates the impact of climate change in water supply sectors. In fact, it has been pointed out by many studies that growth of the population will severely affect the availability and quality of water resources (Conway and Hulme, 1996; Sánchez et al., 2004; Milly et al., 2005; Evans, 2008).

Adaptive capacity. Governance or management policies of water resource and water resource stock have been identified as important determinants of local adaptive capacity. For example, several studies examine the role of governance and political drivers in the water sector vulnerability in various locations (Engle and Lemos, 2010; Sowers et al., 2009). These reforms have ranged from the full-fledged privatization of water systems to different degrees of decentralization and societal participation of water governance in the implementation of adaptive management approaches. In Brazil, the government has implemented a new decentralized water management system which adopts the river basin as the management unit, creates stakeholder-driven river basin councils and consortia, redefines water as a public good with economic value, and seeks to integrate social and ecological systems into water management. Their findings indicate that these governance mechanisms might lead to greater adaptive capacity, and that tradeoffs may exist between some of the variables (e.g., equality of decision making and knowledge availability).

Knowledge of water resource stock and local cultural value of the water resource have been identified as important components of adaptive capacity in water related sectors. For example, Kelkar et al. (2008) finds that community perception of climate driven water stress plays a key role in local vulnerability in India. By using a projection of water availability, they identified four distinct impacts from decreasing water supply in the region such as reduced availability of ground water availability as well as surface water, reduced water quality and declining crop. In the study region, they find that community coping strategy of the water shortage consists of improving access to available water, reduction in demand for water and increasing risk management skills by diversifying crops, occupation and asset portfolio.

Kuruppu (2009) finds that policies that take into account of cultural values on water resource and diversification of water usage may enhance adaptive capacity of water resource to various stresses on water resources in Kiribati. Furthermore, the author argues that adaptation initiatives include possession of water conserving assets such as rainwater tanks, cement lining of open wells and installment of locally designed hand pumps. Table 3 summarizes the possible local vulnerability indicators in water resources.

Table 3. Summary of local vulnerability indicators in water supply sectors

Component	Possible indicators	
Exposure	Droughts Flood and water borne disease Daily precipitation, temperature (mean, min , max) , climate model Mean annual precipitation, mean annual potential evaporation	
Sensitivity	Water dependent sector	Rural agrarian community Biodiversity
	Population	Drinking water increase due to population increase
Adaptive capacity	Economic	Efficient land usage Income Location of housing Flexibility of occupation, migration Diversification of water resource Physical assets (land and soil quality, ground water availability and quality)
	Social	Community network (e.g. irrigation system and cost allocation) Collective action (e.g. church)
	Infrastructure	Irrigation system Access to drinking water Transportation (e.g. road connection) Water storage facilities
	Individual knowledge	Awareness based on past threats Level of education , literacy rate
	Institutional	Government social interventions (conservation, watershed management) Water policy and government intervened pricing

Source: Based on Ludena and Yoon (2015).

3.4 Forest

Exposure. Rising temperature and increasing run-off from increasing rainfall itself have been identified as a key factor affecting vulnerability in the forest sector (e.g. Lal et al., 2011; Rawlani and Sovacool, 2011).

However, the unique exposure measure of the vulnerability studies other than commonly used measures such as climate variability or precipitation stems from the possibility of the pest and insect outbreak (Alig et al., 2004; Gan 2004; Logan et al., 2003; Parkins and Mackendrick, 2007; Tschakert, 2007; Carina and Keskitalo 2008; Kaushik and Khalid 2009; Seidl et al., 2011). In fact, damages to forest resources from pests can be significant (Parkins and Mackendrick, 2007; Kaushik and Khalid, 2009),

Also extreme events such as wild fire driven by climate change have been examined in several literatures (Brown et al., 2004; Ruth et al., 2007).[4] Since many forest resources dependent rural communities tend to be directly impacted by climate change induced wildfires (Karnosky et al., 2005; Triggs et al., 2004).

Sensitivity. Sensitivity of biodiversity has been examined in several studies.[5] More specifically, coastal region where mangrove forests constitute coastal wetlands is extremely vulnerable to sea level rise that has been driven by climate change. Moreover, mangroves in the tropical region are extremely sensitive to global warming (Hay and Mimura, 2006; Kaushik and Khalid, 2009). However, mangroves can act as efficient shields against cyclonic waves, and their conservation is mandatory for any adaptation framework to be developed for coastal zones (Khalid et al., 2008).

Forest dependent communities are also used as a common unit of vulnerability analysis (Carina and Keskitalo, 2008; Fisher et al., 2010; Seidl et al., 2011). In particular, climate impacts on forests may induce market incentives for intensive forest management such as planting, thinning, genetic conservation, tree improvement, and developing wood-conserving technologies. As in the case of agriculture, there are losers and winners. Intensive carbon emissions allow trees to capture more carbon from the atmosphere, resulting in higher growth rates in some regions, especially in relatively young forests on fertile soils (Ryan et al., 2008). The stimulating effect of growth depends on local conditions such as moisture stress and nutrient availability.

Adaptive capacity. The adaptive capacity in the rural community that has been identified as socio-economic component is mainly associated with forest resources (Parkins and

[4] Ruth et al. (2007) predicted that climate change induced wild fire will dramatically increase the fire suppression cost in the state of Washington, U.S.A.

[5] For example, Lal et al. (2011) show that the major concerns of interests are shifts in the forest distribution and types, increased wildfire risk, increased chance of pest attacks and diseases, and adverse impacts on biodiversity.

Mackendrick, 2007; Fisher et al., 2010). For example, Fisher et al. (2010) examine the role of forest product in Malawi that shares safety net characteristics of forest with other tropical countries. According to their studies, forest provides foods to the rural poor to survive famine, and is an important source of cash earnings when faced with weather-related crop failure. The study also finds that low income forest adjacent households and vulnerable population (e.g. age over 65 and/or less educated than their cohorts) are particularly dependent on forests for coping with climatic shocks, probably because they have limited access to other coping mechanisms, such as asset sales.

Table 4 summarizes the possible local vulnerability indicators in the forest sector.

Table 4. Summary of local vulnerability indicators in forest sectors

Components	Possible indicators	
Exposure	Precipitation Pest and insect outbreak Climate change induced disasters (e.g. cyclones, wild fire) High temperature rise	
Sensitivity	Coastal area	Mangrove forest
	Forest dependent communities	Vulnerable population
	Biodiversity	Forest resource
Adaptive capacity	Economic	Income dependency on forest resource (marketable forest resources) Location of housing (e.g. adjacency to forest)
	Individual knowledge	Awareness based on past threats Level of education, literacy rate
	Institutional	Government social interventions (e.g. insect control policy, wild fire control policy)

Source: Based on Ludena and Yoon (2015).

4. Case Studies: Analysis of IDB Development Projects

In this section, we explore whether IDB projects include or can incorporate key vulnerability indicators as those mentioned in the previous section[6]. We seek a possibility to devise indicators that can aggregate and convey sector-specific information at the local project levels, expecting that such indicators can be candidate components of the sectoral index that can be applied systematically for the IDB's project monitoring and evaluation. This section looks into two sets of case studies. First, four case studies are evaluated based on its general characteristics and the three main components of vulnerability, namely exposure, sensitivity and adaptive capacity. Then, we present three case studies where vulnerability indicators are developed under different approaches given the characteristics of each project.

4.1 Analysis of IDB project profiles

We chose four representative projects that directly or indirectly aim to enhance adaptive capacity and reduce vulnerability to climate change in four different sectors (agriculture, coastal zones, water resources, forestry). We analyze the main characteristics of each project, including objective, components and key indicators considered. In addition, we also try to identify whether the project has direct or indirect impacts in improving adaptive capacity to climate change, and whether the project mainly relates to economic development.

For this analysis, we note that adaptive capacity in vulnerable regions can be enhanced through two different channels. The first channel directly builds ability to adapt by providing necessary means. For example, providing local environmental knowledge for farmers to build community readiness of adaptation or building durable physical infrastructure to cope with climate change induced natural disasters can be regarded as necessary means. The other channel indirectly builds adaptive capacity by enhancing economic capability, building physical infrastructure, social capital and upgrading institutional capacity. This indirect channel might be also significant since it targets to manage long-term nature of climate change. In fact, in the vulnerability literature, economic capability represents the economic resources such as human resources, technological alternatives and social capital) that are available to reduce climate change vulnerability (Yohe and Tol, 2002).

[6] The IDB (GN-2650, 2012) defines adaptation to climate change as "activities that increase the capacity of human and natural systems to adapt to a changing climate, and to increase adaptive capacity of human systems and resilience of natural systems; diffusion and dissemination of technologies for related areas; the provision of health services for those disease vectors that will be affected by climate change; climate change vulnerability assessments; technical support and capacity building for climate change adaptation-related policy and economic analyses; and, improved capacity for emergency prevention and preparation for climate-related disasters."

On the other hand, some adaptation projects show that it is very difficult to separate the "development" component of the project from the adaptation to climate change aspects, especially when the project has an attribute of the indirect channel. In general, adaptation projects should have "additionality" characteristics besides "development". Thus, it is also important to identify how an adaptation project has linkages with development.

4.1.1 Provincial Agricultural Services Program (PROSAP III) in Argentina

The main objective of PROSAP III (AR-L1120) is to develop the regional rural economies by increasing the global competitiveness of agricultural products in Argentina (Table 5). The program focuses geographically on non-Pampa areas, where the challenges of irrigation system management, road network coverage, rural electrification, agribusiness promotion, and prevention of adverse climate-related impacts and natural threats are greater than elsewhere in the country.

Argentina provincial agricultural services program aims to ultimately improve household income by raising market competitiveness and local infrastructure which could enhance the ability to cope with climate change related impacts and threats. Since we find that the program enhanced adaptive capacity through increasing income of agricultural household in the vulnerable region and triggered development of region's infrastructure that increased competitiveness of agricultural products, possible quantifiable measures for change in adaptive capacity could be household income change, change in export value of local agricultural products and climate change-related net benefit from newly built infrastructures. In fact, investment in infrastructure includes amount of roads that was built, new irrigation system installed and increased electrification coverage.

Unlike adaptive capacity, finding quantifiable factors of vulnerability to climate change from this project proposal is a difficult task since the project document lacks information on the specific exposure and sensitivity measure of vulnerability. We need relevant information whether the program tried to tackle the adverse effect of the climate variability or climate change induced specific natural disasters. For example, we need information of climate variability itself or climate related natural disasters such as droughts. Without the exposure measure, it is difficult to evaluate or extract the role of the project on reducing vulnerability to climate change.

We find that the project has indirect channels in improving adaptive capacity to climate change, and is generally related to economic development.

Table 5. Main characteristics of IDB project "Provincial Agricultural Services Program" (AR-L1120)

Characteristic	Description
Name	Provincial Agricultural Services Program - PROSAP III
Country	Argentina
Sector	Agriculture
Type of financing	Loan
Amount (US$ million)	287.5 (IDB: 230.0, Local 57.5)
Approval year and Status	2011 (Implementation)
Objective	To develop the regional rural economies by making them more competitive and increasing their agricultural exports
Components	• Infrastructure and agrifood services: roads, power grids, irrigation, drainage, productive revitalization • Agribusiness competitiveness: development of agrifood clusters and incentives • Competitive cluster development subcomponent: development of agroindustrial clusters, interagency collaboration networks and enhancement plans, etc.
Key indicators considered	• Regional agricultural exports as a percentage of total agricultural exports • Increase in yield per hectare for beneficiary producers • Decrease in transportation costs • Decrease in production losses • Number of producers benefited by type
Direct or indirect channels for improving adaptive capacity	Indirect
Is the project mainly related to economic development?	Yes

Source: IDB document (AR-L1120)

4.1.2 Coastal Risk Assessment and Management Program (CRAMP) in Barbados

The main objective of CRAMP in Barbados (BA-L1014) is to build adaptive capacity to climate change of coastal sector in Barbados (Table 6). The project could to enhance adaptive capacity through variables that empirical literature commonly uses such as improving risk management ability, infrastructure and institutional capability.

Carina and Keskitalo (2008) argue that vulnerability and adaptive capacity are location-specific and many decisions regarding climate-induced risks are made at those levels. Hence, if applicable, assessments of vulnerability and adaptive capacity should also include the context of other ongoing changes of social risks, such as globalization that will impact communities and exacerbate their vulnerabilities. In fact, risk management ability is already quantified through the IDB's risk management index.

According to the CRAMP loan document, various investments in infrastructure are recorded and most of them are quantified in monetary terms. These investments include improvement of roads, construction of shoreline stabilization structures (e.g. sand dunes and coral reefs), construction of coastal revetments, offshore breakwaters and beach nourishment as well as shoreline enhancement structures (e.g. walkways), and restoration of the Hole town Lagoon to improve water quality and reduce flooding using a system to improve water exchange between the lagoon and the ocean.

Furthermore, the literature shows that institutional capacity is one of the major components of adaptive capacity in the coastal sector. In fact, the CRAMP builds institutional capacity by training in enforcement for coastal zone inspectors, developing policy for information sharing and executing public education and awareness campaign on disaster risk. All of these regulatory measures may be quantified through household surveys.

Vulnerability assessments can also be performed since the program identifies multiple exposure measures such as hurricanes and tropical storms and, resulting directly from these, storm surges, coastal erosion, sea level rise and high winds. These multiple exposure of climate induced hazards can be quantified through number of occurrence and intensity of events.

Table 6. Main characteristics of IDB project "Coastal Risk Assessment and Management Program" (BA-L1014)

Characteristic	Description
Name	Coastal Risk Assessment and Management Program (CRAMP)
Country	Barbados
Sector	Coastal zones
Type of financing	Loan
Amount (US$ million)	42 (IDB: 30; Local: 12)
Approval year and Status	2010 (Implementation)
Objective	To build capacity in integrated coastal risk management through disaster risk reduction and climate change adaptation in development planning, control and monitoring of the coastal zone
Components	• Coastal risk assessment, monitoring and management • Coastal infrastructure: construction of hazard-resilient shoreline access and stabilization works • Institutional sustainability for the integrated coastal risk management: creation of enabling policy and regulatory environment, institutional capacity building, stakeholder communication and education
Key indicators considered	• Increase in risk management performance as measured by the Risk Management Index (RMI)* * This index is one of the IDB Indicators of Disaster Risk Management measuring the performance in risk management in terms of the four policy areas of risk identification, risk reduction, disaster management, and governance and financial production.
Direct or indirect channels for improving adaptive capacity	Direct
Is the project mainly related to economic development?	No

Source: IDB document (BA-L1014)

4.1.3 Bahia Environmental Development Program (BEDP) in Brazil

The empirical literature on vulnerability and adaptive capacity assessment in the water sector generally measures enhanced and improved water sanitation. In this case, the BEDP in Brazil aims to improve efficiency in water supply through political regulation (i.e. granting license on limited water resource) and to improve quality of supplied water by preventing waste disposal. These regulatory policy measures can be regarded as institutional capability which is often represented in the literature by the political leadership and governance structure, disaster prevention systems, and climate change policy (Table 7).

For example, systems of local water supply and distribution, early warning systems, accessibility to relevant information, and availability of crisis management programs and policy (McCarthy et al., 2001) are part of adaptive capacity. The policy measure may be quantified by measuring percentage of households with improved water supply and percentage of households with improved sanitation. Vulnerability assessment can be also done since the BEDP finds the region is vulnerable to environmental degradation such as soil erosion, this exposure measure can be also quantified by measuring dimension of the degraded area.

However, whether these vulnerability measures are related to climate change is questionable. In order to assess the role of the program on reducing vulnerability to climate change, we need information on a climate driven exposure measure and/or direct impact of climate change on environmental degradation. For example, it would be useful if we find that climate driven precipitation change as one factor that caused environmental degradation in the water sector. Unfortunately, the project proposal does not provide relevant information on causal relationship between environmental degradation and climate change.

Table 7. Main characteristics of IDB project "Bahia Environmental Development Program" (BR-L1103)

Characteristics	Description
Name	Bahia Environmental Development Program (BEDP)
Country	Brazil
Sector	Water resources
Type of financing	Loan
Amount (US$ million)	16.7 (IDB: 10.0, Local: 6.7)
Approval year and Status	2010 (Implementation)
Objective	To support the conservation and sustainable use of natural resources, especially water resources in the State of Bahia
Components	• Strengthening of Environmental Department (SEMA): technical assistance, studies, equipment and training • Environmental management for sustainable development in the environmental protection areas (EPAs): comprehensive environmental management plans, training for management councils, installation of environment offices and EPA offices, surveys of areas of special socio-environmental interest in the Metropolitan Region of Salvador
Key indicators considered	• Increase in beneficiaries' level of satisfaction with SEMA • Increase in the efficiency of granting environmental licenses within the time limits established in the current regulations • Environmental degradation process is reduced in the EPA in the program • Implementation of priority actions in the EPAs' management plans
Direct or indirect channels for improving adaptive capacity?	Direct
Is the project mainly related to economic development?	No

Source: IDB document (BR-L1103)

4.1.4 Integrated Watershed Management in Lakes Apanas and Asturias (IWMLAA) in Nicaragua

The purpose of this project is to foster forest and biodiversity conservation in the Lakes Apanas and Asturias Watershed (Table 8). The project will do that based on two components. First, the implementation of Sustainable Forest and Land Management (SFLM) activities that will increase forest carbon sequestration, reduce greenhouse gas emissions and protect fragile ecosystems. Second, the design and piloting of a scheme of Payment for Environmental Services (PES) directed to farmers and/or private owners of forested reserves to be financed by the compensation for water use to be made by the hydroelectric power within the watershed.

The project targets both efficient management of forest and land resource and future reduction of climate change. In fact, the proposal of the project already specifies how the project would improve quantifiable indicators of adaptive capacity. These include; i) training communities in business plan development, sustainable forestry management and strategy in timber value chains; ii) training local producers on sustainable forestry; iii) implementing carbon monitoring system; iv) implementing biodiversity monitoring system and biodiversity conservation farms (orchids, butterflies, frogs and iguanas); v) building ecotourism lodging facilities; vi) conduct economic valuation of ecosystem services within the watershed and vii) forest plantations.

One drawback of the project is that the proposal does not provide the specific exposure and sensitive measure and as a result vulnerability assessment could be difficult. It is worth noting that exposure of biodiversity to climate change has been examined in several studies, including wild fire, pest and insect outbreaks, among others.

Table 8. Main characteristics of the IDB project "Integrated Watershed Management in Lakes Apanás and Asturias" (NI-X1005)

Characteristic	Description
Name	Integrated Watershed Management in Lakes Apanás and Asturias (IWMLAA)
Country	Nicaragua
Sector	Forest (Biodiversity)
Type of financing	Non-reimbursable investment grant
Amount (US$ million)	8.9 (IDB/GEF: 4.0, Local cofinancing: 4.9)
Approval year and Status	2011 (Implementation)
Objective	To foster forest and biodiversity conservation in the Apanás and Asturias Watersheds, important for hydroelectricity generation
Components	• Strengthening the institutional framework and local capacities for land-use planning, soil conservation practices, and integrated watershed management • Implementation of sustainable land and forestry management practices enhancing biodiversity conservation and carbon sequestration • Conservation of the forest and biodiversity in Private Nature Reserves (PNR) and the RAMSAR site • Design and implementation of the mechanism of Payments for Environmental Services (PES) in the Apanas Watershed
Key indicators considered	• Hectares under improved sustainable land and forest management practices increased • Avoided/sequestered tons of CO2e of direct emissions from program activities • Annual tons of dragged sediments per prioritized micro watershed reduced • Hectares of forested area within the PNR network increased • Hectares of forest protected under a PES mechanism increased
Direct or indirect channels for improving adaptive capacity?	Direct
Is the project mainly related to economic development?	No

Source: IDB document (NI-X1005)

4.2 Development of vulnerability indicators for IDB projects

Overall, in the previous section we find that all selected project proposals have a number of key vulnerability indicators considered, mostly related to adaptive capacity. However, we observe that three of the IDB project proposals in a general sense lack of the information on the exposure and sensitivity measures. In case that the exposure measure is missing, it becomes extremely difficult to generate indicators for vulnerability since the object of vulnerability is missing. In addition, although the exposure of vulnerability to climate change is identified, we need to identify to what extent the region is exposed to climate variability or climate change induced environmental hazards. One proposal (CRAMP) contains significant indicators for vulnerability assessment including the exposure and sensitivity measure.

Based on the previous analysis, and the limitations regarding the inclusion of vulnerability indicators, we present a set of case studies that developed vulnerability indicators at the project level. The next section summarizes three case studies that were developed under an IDB funded initiative regarding the measurement of vulnerability at the project level. More detail on the cases presented in this section can be consulted in the cited papers.

4.2.1 Development Program in the Southwest Region of the State of Tocantins (PRODOESTE) in Brazil

The Development Program in the Southwest Region of the State of Tocantins (PRODOESTE) (BR-L1152) aims to improve water supply and provide technical support to farmers located in Southwest Tocantins in Brazil. The project intends to increase crop yields, promote agricultural and agribusiness production, employment and to increase the income and welfare of region inhabitants through the development of the irrigation and drainage infrastructure and other basic infrastructure (roads, electricity, potable water). PRODOESTE covers 14 municipalities of the 139 municipalities of the State of Tocantins. During the first stage, PRODOESTE will irrigate 7,100 hectares located in the Pium and Riozinho river basins. Farmers with land, who plot between 160 ha and 19,700 hectare are the main Program beneficiaries; they usually crop rice, soybeans, watermelon, beans, sunflower and corn. Table 9 provides a summary of the project information.

Guerrero-Escobar et al. (2015) assess local vulnerability to climate change in agriculture for those municipalities where PRODOESTE program operates. They evaluate the potential impact of climate change on the agricultural systems' crop yields and related it to Tocantins farmer's profits. Given that the Brazilian statistical agency (IBGE) measures yields on a more continuous basis, the authors focus on yields rather than land values, or directly on profits. Although vulnerability is not directly assessed as a monetary function, they convert the vulnerability indicator to monetary values. The main advantage of these indicators is that they can be applied to cases where there is publicly available data on crop yields, farmers' profits and weather data.

The proposed indicator of local vulnerability includes the assessment of exposure, sensitivity, vulnerability and adaptation (the capacity to build resilience), capturing systems' dynamics on intensity and how climate events modify adaptive capacity. The flexibility of the indicator allows ranking systems with different yield performance, different exposure to climate risk and different levels of sensibility. Thus, even when two systems show the same level of exposure, their vulnerability indicators can differ depending on yield performance and sensitivity.

The vulnerability indicator is composed of two parts, exposure and sensitivity, and it is measured at the system-level, in this case the municipality-level. System exposure is measured as the probability that temperature and precipitation (the stressors) fall outside a given range that is appropriate for crop development. Thus, exposure measures the propensity of the system to be damaged. Sensitivity is computed as the marginal effect of the stressor on crop yields, weighted by the inverse ratio of the yield to a threshold yield which represents the yield level below which the system is damaged or, in economic terms, the crop investment is lost. Hence, sensitivity will be higher if the marginal effect of the stressor on the crop yield is high and the closest the average crop yield is to the threshold. Vulnerability is then calculated for each stressor, temperature and precipitation, as the expected value of the sensitivity measure, where the expectation is taken over the exposure domain. In general terms, it measures the expectation that the system can be damaged as a response of changes in the stressors (temperature and precipitation).

In order to convert the measures into monetary values, the authors estimate the profits-yield elasticity for each of the crops evaluated and weight the vulnerability measures by the profits-yield elasticity. The study baseline results indicate that PRODOESTE's municipalities present medium to high levels of precipitation and temperature vulnerability. In general terms, the South side of PRODOESTE shows the largest vulnerabilities to precipitation and the east side presents the highest temperature vulnerabilities.

Finally, the authors perform an adaptation exercise related to irrigation where the sample was divided between municipalities that have a percentage of farms with irrigation higher than the average in the region (High Irrigation) and municipalities that have a percentage of farms with irrigation lower than the average (Low Irrigation). Then, they re-estimate the vulnerability measures for Low Irrigation areas and impute the sensitivity values of the High Irrigation areas into the Low Irrigation areas. This allowed to obtained a vulnerability measure accounting for adaptation. In general terms, the results of this exercise show that with adaptation measures such as irrigation, vulnerability will be reduced, especially in the long-term.

Table 9. Main characteristics of IDB project "Development Program in the Southwest Region of the State of Tocantins" (BR-L1152)

Characteristic	Description
Name	Development Program in the Southwest Region of the State of Tocantins (PRODOESTE)
Sector	Agriculture and Rural Development (Irrigation and Drainage)
Country	Brazil
Type of financing	Loan
Amount (US$ million)	165 (IDB: 99, Local: 66)
Approval year and Status	2010 (Implementation)
Objective	To support the sustainable development of the southwest region of the State of Tocantins through the development of the irrigation and drainage infrastructure and other basic infrastructure (roads, electricity, potable water) to promote agricultural and agribusiness production, employment and to increase the income and welfare of region inhabitants.
Components	• Productive Water Infrastructure for the sub-watersheds of rivers Riozinho Pium, which aims to storage, transmission and distribution of water necessary to meet the needs of agriculture during an annual hydrological cycle in an area of 38,800 hectares; Improvement and expansion of the road transportation network, improving housing and equipment and support services. • Promoting Regional Development through investment promotion; strengthening productive chains; information centers and support for the establishment of new businesses; organization of producers; support for research applied to the conditions of the river valleys. • Environmental Management of Water Resources including tracking and monitoring of water resources, Plan for water resources of the basins of the rivers and Riozinho Pium and management and recovery of degraded areas. • Institutional Strengthening for operation and maintenance of the irrigated areas; implementation of pricing policies and cost recovery for water use; defining and implementing models of management for water resources.
Key indicators considered	• Regional crop yields per hectare • Farmers' profits as a function of yields • Cumulative precipitation and average temperature as stressors variables
Direct or indirect channels for improving adaptive capacity?	Direct
Is the project mainly related to economic development?	Yes

Source: IDB document BR-L1152.

4.2.2 National Irrigation Program with a Watershed Approach (PRONAREC) in Bolivia

PRONAREC's objective was to increase agricultural yields and incomes through investment in irrigation systems. The project started in 2009 and was completed by 2014. The project included the construction of 100 micro irrigation systems and 10 irrigation programs providing irrigation for 8,000 hectares of agricultural land without access to irrigation systems. The target population was 5,000 small farmers in the Altiplano, Chaco, Valle and lowlands in the eastern Santa Cruz region, which includes areas of the country that are most poor and most vulnerable to droughts. Table 10 provides a summary of the project details.

Based on the project information, Andersen, Cardona and Romero (2015) tried to establish whether the irrigation systems have contributed to an increase in general resilience in the areas benefiting from new irrigation infrastructure. The two indicators proposed by the authors to measure general vulnerability/resilience were per capita household income and level of household income diversification, as measured by the Diversification Index. These indicators were calculated for all households both before and after treatment.

The quantitative analysis presented in this case study shows significant increases in both the level and the diversification of incomes among agricultural households in Bolivia between 2002 and 2012. This suggests that Per Capita Income and the Diversification Index are useful and practical indicators to track changes in these two key dimensions of vulnerability.

The study also shows that it is possible to use these indicators to evaluate changes in vulnerability due to specific interventions, in this case irrigation projects. Using econometric methods (OLS and Propensity Score Matching) to control for possible differences in pre-treatment characteristics, the authors tested whether changes over time in the two key vulnerability indicators differed between households located in municipalities that have benefitted from PRONAR or PRONAREC irrigation projects and households located in municipalities that have never benefitted from such projects (difference-in-difference estimation).

In order to understand the pathways to reduced vulnerability, as well as the potential obstacles to achieving the desired results, Andersen, Cardona and Romero (2015) demonstrated the usefulness of developing an explicit Theory of Change, detailing how the intervention is expected to affect the vulnerability indicators. This also helps the selection of appropriate intermediate indicators.

Table 10. Main characteristics of IDB project "National Irrigation Program with a Watershed Approach" (BO-L1021)

Characteristic	Description
Name	National Irrigation Program with a Watershed Approach
Country	Bolivia
Sector	Agriculture and Rural Development
Type of financing	Loan
Amount (US$ million)	30.6 (IDB: 25, Local: 5.6)
Approval year	2009
Objective	Improve agricultural production and productivity to help reduce poverty and increase the income of the beneficiaries. The purpose of the program is to increase the area under irrigation and improve the efficiency, equity, sustainability and productivity of water use and soil for agricultural purposes.
Components	• Investments to develop community irrigation; improving infrastructure in irrigation and micro-irrigation. • Irrigation water management with a focus on basins: i) assignment and registration of rights to use water; ii) establishment of an information system on water resources and water use rights; iii) strengthening water organizations to improve farm irrigation practices, self-management, operation and maintenance; and iv) strengthening the services provided by the new institutions.
Key indicators considered	• Per capita household income • Level of household income diversification, as measured by the Diversification Index.
Direct or indirect channels for improving adaptive capacity?	Direct
Is the project mainly related to economic development?	Yes

Source*:* IDB document (BO-L1021)

4.2.3 Sustainability of Water Supply and Sanitation Services in Rural Communities III in Mexico

The Sustainability of Water Supply and Sanitation Services in Rural Communities III project (ME-L1050) was implemented in rural and urban communities in Mexico between 2011 and 2014. This program supported the efforts of the Government of Mexico to increase coverage and improve the quality of drinking water and sanitation in Mexican towns with up to 10,000 inhabitants (Table 11). For rural areas of up to 2,500 people, the focus was to encourage community management systems of water and sanitation infrastructure, while in the towns of 2,501 to 10,000 inhabitants the focus was to design and implement sustainable management schemes according to the characteristics of the locality, taking priority areas as those of high and very high marginalization. In parallel, institutional strengthening at local and state levels, and promoting trust among community members, supported by appropriate national coordination, and decentralization of responsibilities and resources were implemented in the context of the project.

For this project, Haruna et al. (2015) use a multi criteria process which involves the identification of all possible drivers of climate change vulnerability and a subset of the possible elements within each diver. This allows viewing adaptation planning from a systems perspective. The process-based methodology attempts to capture a systems' flow data, thus allowing for dynamism within the projects' context. Special emphasis is placed on the multiple scales at which vulnerability drivers interact, dynamics within local systems, diversity of the local systems, quality and availability of technology, and adaptation financing. The authors categorize drivers according to the components of vulnerability - exposure, sensitivity and adaptive capacity. In each of these categories were identified the drivers by project component and sector. For instance, drivers of vulnerability to climate change in the water and sanitation sectors include among other things, the frequency of extreme events such as flooding or dry conditions that may impact water availability

Based on the case study by municipalities, Haruna et al. (2015) found out that effectively reducing local vulnerability to climate change and/or increasing local adaptive capacity differs from locality to locality and from context to context. Therefore, the role of location specific, readily available information and methods for informed decision making is imperative.

Table 11. Main characteristics of the IDB project "Sustainability of Water Supply and Sanitation Services in Rural Communities III" (ME-L1050)

Characteristic	Description
Name	Sustainability of Water Supply and Sanitation Services in Rural Communities III
Sector	Water and Sanitation- Water Supply
Country	Mexico
Type of financing	Loan
Amount (US$ million)	500 (IDB: 250; Local: 250)
Approval year	2011-2014
Objective	To support the efforts to increase coverage and improve the quality of drinking water and sanitation in Mexican towns with up to 10,000 inhabitants
Components	• Investments in Infrastructure: Building Water Supply Systems and Sewer Solution Systems based on technical- economic convenience; Preparation and implementation of pilot projects for use of treated wastewater for small-scale agricultural use. • Community Development: Design and implementation of social care plans focused on the creation and/or strengthening of community-based organizations responsible for the provision of water services • Institutional Strengthening: including capabilities of planning, implementation, monitoring and evaluation of government agencies; analysis of a financial mechanism that enables the continuity and timeliness of counterpart funds from federalized resources
Key indicators considered	• Extreme events, precipitation, temperature, evaporation • Water sector, sensitive infrastructure, population • Economic resources, social capital, infrastructure, technology, human capital, governance and institutions, adaptation finance
Direct or indirect channels for improving adaptive capacity?	Indirect
Is the project mainly related to economic development?	Yes

Source: IDB document (ME-L1050)

5. Policy implications

Most of the attention on vulnerability indices has been focused on the national level with some emphasis at the sector level. These generic indices are useful especially when comparing at the country level, but lack usefulness for practitioners when going at the regional or local level. Considering this, we conducted an analysis of the literature on vulnerability indicators, and also explored whether selected case studies (IDB projects) related to adaptation to climate change have information on measuring vulnerability.

The paper shows the importance of assessing vulnerability to climate change based on the local indicators, as most adaptation projects are implemented at the local level. We find that some indicators can be adopted across different sectors as a proxy to measure local vulnerability. For example, many studies adopt similarly quantified variables such as composition of wealth/income, communal governance and age distribution of local population in adaptive capacity as well as natural events derived from climate change in exposure and sensitivity. We also confirm that the inclusive information from the related literature should be used for the choice of influential variables in designing a specific climate change project.

From the first set of case studies of IDB projects, we conclude the following. First, all of the selected project proposals consider various key indicators necessary for designing, implementing, monitoring and evaluating the projects, mostly focused on measuring adaptive capacity. Therefore, we suggest that the project proposals include the indicators of measuring exposure and sensitivity to climate change. For example, the time series data of climate variability in the vulnerable region needs to be scientifically traced to measure the extent of the impact of the extreme climate. Second, identification of quantifiable measure of adaptive capacity to climate change needs to be different from that of pure development projects. Some adaptive capacity measure such as a change in economic capacity, often measured as an increase in income, is likely to be misleading since the resulting increase in investment for economic development may lead to an increase in environmental hazards. Only if the increased income is properly allocated to reduce vulnerability to climate change, the growth of income can be regarded as adding adaptive capacity for sustainable development.

The development of vulnerability indicators at the project level also has important implications for climate finance. As more interest and resources move towards financing climate adaptation projects, there is an increased need to monitor and evaluate the effectiveness of the projects and the use of limited resources towards climate change adaptation. The development of indicators at the project level would allow showing results for these projects and measuring the effectiveness of interventions in adaptation. For IDB, this has increased relevance, as it announced in 2015 the goal of doubling the volume of its climate-related financing by 2020, as well as screen all relevant projects for climate risks and resilience starting in 2018.

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