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The assessment of climate change related vulnerability in the agricultural sector: Reviewing conceptual frameworks

by

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- DRAFT -

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1. Context and objectives of the paper

Climate change is expected to impact on the agricultural sector in multiple ways, among others through increased variability with regard to temperature, rain, frequency and intensity of extreme weather events, changes in rain patterns and in water availability and through perturbations in ecosystems. Main effects on agricultural production are expected to be an increased variability of production, decrease of production in certain areas and changes in the geography of production. One way to cope with the challenges comprised by climate change is to build resilience for adaptation in the agriculture sector.

The OECD and the FAO are working together on an analytical report that focuses on building resilience in agricultural production systems in the context of climate change. The report intents to respond to key policy concerns regarding climate change, its impact on agriculture and the implications for food security. For the analytical report a general overview on climate change related risks and vulnerabilities will be provided by other contributors to the report. Furthermore, in order to illustrate specificities relative to addressing risks and vulnerability in agriculture, four thematic case studies will be carried out, capturing agricultural production systems in both developed and developing countries.

In the context of the analytical report the objective of this paper is to provide a review of conceptual frameworks for the assessment of climate change related vulnerability and give some examples of their application to the agricultural sector. Therefore the paper reviews existing interpretations, concepts and frameworks of vulnerability approaches in the climate change context. However, it has to be highlighted that the paper does not attempt to give a complete literature review on the vast interpretations and alternative concepts of vulnerability approaches. Instead, the paper rather aims to give a brief overview on main characteristics in vulnerability approaches, highlight major differences in alternative vulnerability interpretations, and give some reference examples for the agricultural sector. In doing so, the paper aims to (i) help reducing complexity by easing understanding and communication, (ii) assist the comparison of different vulnerability approaches to identify differences and detect gaps, and (iii) serve as a guiding principle and useful reference for vulnerability assessment in the agricultural sector.

The paper is structured as follows. The basic meaning of vulnerability and its three components in the climate change context (exposure, sensitivity and adaptive capacity) are described and the difference between adaptive capacity and coping range is depicted in section 2. In section 3 alternative interpretations and concepts of vulnerability are presented, highlighting the relative roles of natural and social science within the different concepts. Section 4 gives a further characterisation of current and future vulnerability in order to underline the differences with regard to the temporal reference in vulnerability concepts and interpretations. Some methods for assessing vulnerability to climate change are noted in section 5, focusing briefly on the use of indicators, model based assessments and stakeholder involvement in vulnerability assessments. Section 6 briefly refers to the importance of documenting data constraints and uncertainties related to an assessment of vulnerability. Section 7 presents concluding remarks and a framework table with the elements that have to be considered and addressed in assessments of climate change related vulnerability in the agricultural sector.

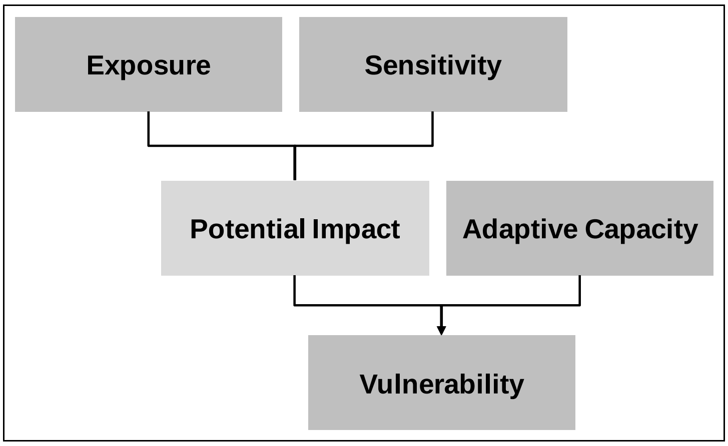
2. What is vulnerability to climate change?

The literature provides a vast variety of definitions for vulnerability, mostly depending on the disciplines of their origin (Adger, 2006). Nelson et al. (2010) pointed out that definitions of vulnerability should not be confused with conceptual frameworks. While definitions describe the components of vulnerability, conceptual frameworks give meaning to the definitions so that they can be analysed according to the analytical context in a transparent and repeatable way (Nelson et al., 2010). However, it is essential to first clarify and understand what is meant when vulnerability is spoken and written about in the climate change context (Eakin and Luers, 2006, Janssen and Ostrom, 2006). A consistent and transparent terminology helps to facilitate the collaboration between different researchers and stakeholders, even if there are differences in the conceptual models applied (Downing and Patwardhan, 2005, Füssel, 2007, cf. Laroui and van der Zwaan, 2001, Newell et al., 2005).

The Intergovernmental Panel on Climate Change (IPCC) is considered to be the leading scientific international body for the assessment of climate change, and consequently the starting point for this paper is vulnerability as defined by the IPCC. According to the IPCC (2007) definition, vulnerability in the context of climate change is "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity" (IPCC, 2007, Glossary). Thus, agricultural vulnerability to climate change can for example be described in terms of exposure to elevated temperatures, the sensitivity of crop yields to the elevated temperature and the ability of the farmers to adapt to the effects of this exposure and sensitivity, by for example planting crop varieties that are more heat-resistant or switching to another type of crop (c.f. Schröter et al., 2005).

The definition of the IPCC (2007) specifically highlights three components of vulnerability in the climate change context: exposure, sensitivity and adaptive capacity (graphically depicted in figure 1). It implies that a system is vulnerable if it is exposed and sensitive to the effects of climate change and at the same time has only limited capacity to adapt. On the contrary, a system is less vulnerable if it is less exposed, less sensitive or has a strong adaptive capacity (Smit et al., 1999, Smit and Wandel, 2006).

Figure 1: Vulnerability and its components



Source: modified from Allen Consulting (2005, p.20)

In the climate change context, *exposure* relates to "the nature and degree to which a system is exposed to significant climatic variations" (IPCC, 2001, Glossary). Exposure represents the background climate conditions and stimuli[1] against which a system operates, and any changes in those conditions. Thus, exposure as a component of vulnerability is not only the extent to which a system is subjected to significant

[1] Climate-related stimuli are "all the elements of climate change, including mean climate characteristics, climate variability, and the frequency and magnitude of extremes" (IPCC, 2001, Glossary).

climatic variations, but also the degree and duration of these variations (Adger, 2006). For vulnerability assessments the climatic variations can be aggregated as climate variability or specific changes in the climate system (e.g. temperature increases, variability and change in rainfall, etc.). It has to be noted that systems are often exposed to natural climate variability, independent of future climate changes; however, climate change can alter and increase the future exposure (Lavell et al., 2012). With regard to exposure it is also important to define the exposure unit, i.e. the activity, group, region, or resource that is subjected to climate change (IPCC, 2001, Glossary).

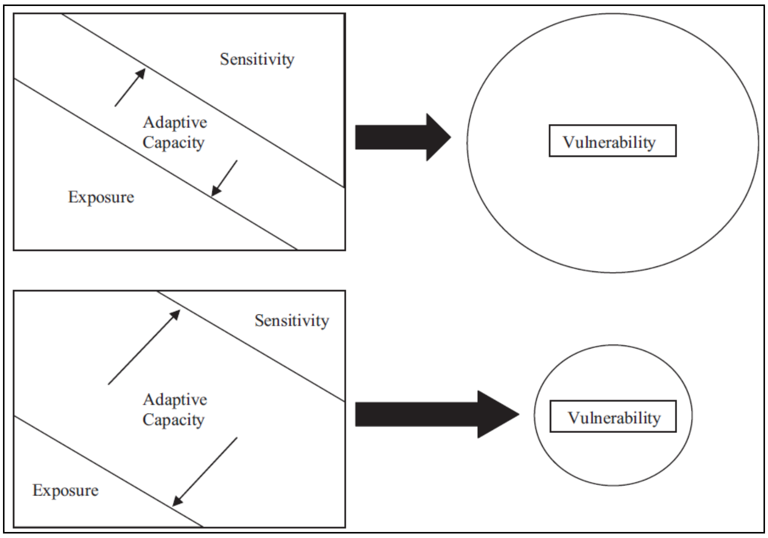
The *sensitivity* of a system to climate change reflects the "degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea level rise)" (IPCC, 2007, Glossary). Sensitivity reflects the responsiveness of a system to climatic influences, and the degree to which changes in climate might affect it in its current form. Thus, a sensitive system is highly responsive to climate and can be significantly affected by small climate changes.

Exposure and sensitivity together describe the potential impact that climate change can have on a system. However, it has to be noted that even though a system may be considered as being highly exposed and/or sensitive to climate change, it does not necessarily mean that it is vulnerable. This is because neither exposure nor sensitivity account for the capacity of a system to adapt to climate change (i.e. its adaptive capacity), whereas vulnerability is the net impact that remains after adaptation is taken into account (cf. Figure 1). Thus, the adaptive capacity of a system affects its vulnerability to climate change by modulating exposure and sensitivity (Yohe and Tol, 2002, Gallopin, 2006, Adger et al., 2007).

The IPCC (2007) defines *adaptive capacity* as the ability (or potential) of a system to successfully adjust to climate change (including climate variability and extremes) to (i) moderate potential damages, (ii) to take advantage of opportunities, and/or (iii) to cope with the consequences (IPCC, 2007, Glossary). Adaptive capacity comprises adjustments in both behaviour and in resources and technologies (Adger et al., 2007). Recent literature emphasises the importance of socio-economic factors for the adaptive capacity of a system, especially highlighting the integral role of institutions, governance, and management in determining the ability to adapt to climate change (Smith and Pilifosova, 2001, Brooks and Adger, 2005, Adger et al., 2007, Engle, 2011, Williamson et al., 2012). Accordingly, the adaptive capacity of a system can be fundamentally shaped by human actions and it influences both the biophysical and social elements of a system (IPCC, 2012). Research points out that some socio-economic determinants of adaptive capacity are generic (like e.g. education, income and health), whereas other determinants are specific to particular climate change impacts such as floods or droughts (like e.g. institutions, knowledge and technology) (Adger et al., 2007). In general, the determinants are not independent of each other nor are they mutually exclusive, as for example economic resources facilitate the implementation of new technologies and may ensure access to training opportunities. Lower levels of adaptive capacity in developing countries are very often associated with poverty (Handmer, 1999, IPCC, 2012).

Adaptive capacity is generally accepted as a desirable property or positive attribute of a system for reducing vulnerability (Engle, 2011). The more adaptive capacity a system has, the greater is the likelihood that the system is able to adjust and thus is less vulnerable to climate change and variability. The basic role of adaptive capacity in influencing vulnerability is depicted in Figure 2.

Figure 2: The basic role of adaptive capacity in influencing vulnerability



Source: Engle (2011, p.650)

Vulnerability, its three components (exposure, sensitivity, adaptive capacity) as well as their determinants are specific to place and system and they can vary over time (i.e. they are dynamic), by type and by climatic stimuli (e.g. increasing temperature, droughts, etc.) (Smit and Wandel, 2006, Adger et al., 2007). Thus, vulnerability is context specific, and the factors that make a system vulnerable to the effects of climate change depend on the nature of the system and the type of effect in question (Brooks et al., 2005), i.e. the factors that make farmers in semi-arid Africa vulnerable to drought will usually not be identical to those that make farmers in Northern Europe vulnerable to extreme weather events.

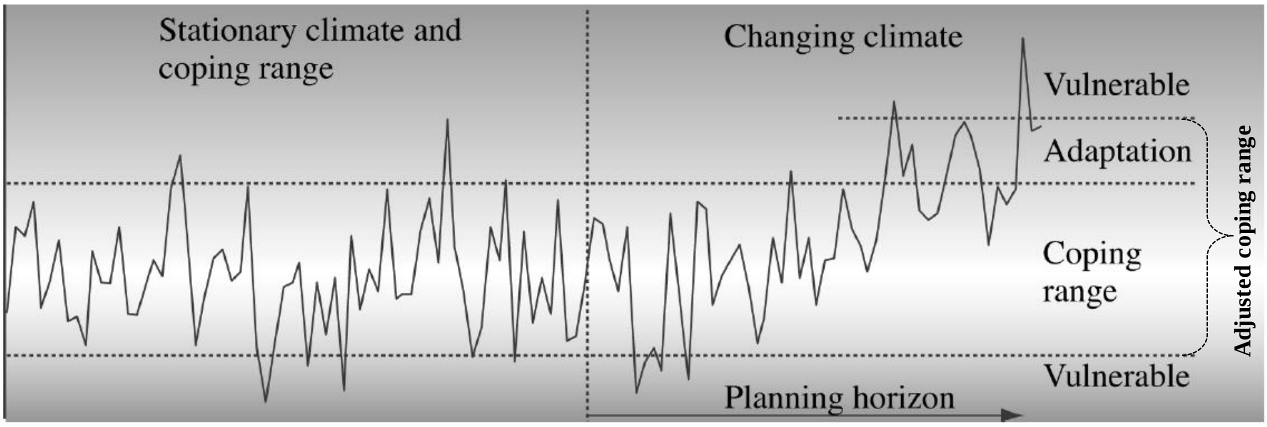
Adaptive capacity versus coping range

It is important to distinguish between adaptive capacity and coping range because both concepts are associated with different time scales and represent different processes (Smithers and Smit, 1997, Folke et al., 2002, Eriksen and Kelly, 2007). A certain extent of variability is an inherent characteristic of climate and most social and economic systems (including agriculture) are able to cope with some variations in climatic conditions, however mostly not with extremes of climate variability. The capacity of a system to accommodate deviations from “normal” climatic conditions describes the “coping range”, which can vary among systems and regions. Towards the edges of the coping range outcomes might become negative but are still tolerable, whereas beyond the coping range (i.e. beyond the vulnerability or critical threshold) the tolerance of the system is exceeded and it runs into a vulnerable state (Smit and Pilifosova, 2001, Yohe and Tol, 2002, Jones and Mearns, 2005, Carter et al., 2007, cf. Figure 3). For example, agricultural activities depend on local weather and climate conditions and can cope with some variability in these conditions, e.g. if it rains more or if it is drier over a given period of time (such as a specific month, season or year). However, if the conditions become too extreme (e.g. heavy rainfall, floods or extended droughts) and exceed the coping range, than this may result in severe effects for productivity levels and diminish livelihoods.

Understanding the coping range and vulnerability thresholds of a system is a prerequisite for the assessment of likely climate change impacts and the potential role of adaptation. Coping range and adaptive capacity of a system are certainly related, but it is important to distinguish between the two concepts when attempting to measure the ability of a system to respond to adverse consequences of climate change (Eriksen and Kelly, 2007). The concept of the coping range is a practical conceptual model because (i) it fits the mental models that most people have with regard to risk and (ii) it helps linking the understanding of current adaptation to the climate and adaptation needs under climate change (Jones and Boer, 2005, Jones and Mearns, 2005, Carter et al., 2007). In contrast, adaptive capacity defines (i) the preconditions (including social and physical elements) that are necessary to enable adaptation and (ii) the ability to mobilise these elements (Nelson et al., 2007).

Adaptive capacity represents the potential of a system to adapt rather than the actual adaptation (Brooks, 2003). In turn, adaptation represents the adaptation actually realised or aimed at to be realised in the future. This implies that through adaptation the coping range of a system can be expanded (or adjusted). Thus, the coping range as presented in the left part of figure 3 represents the capability of a system to deal with current variations in climatic conditions. This coping range can be adjusted through adaptation, which in turn reduces the vulnerability of a system in the future (right part of figure 3)[2]. Hence, the coping range represents one component of adaptive capacity (with the adaptive capacity going beyond the actual coping range) and any adaptation can only take place within the adaptive capacity of a system.

Figure 3: Relationships between climate change, coping range, vulnerability thresholds and adaptation



Source: slightly modified from Jones and Mearns (2005, p.132) by adding the adjusted coping range

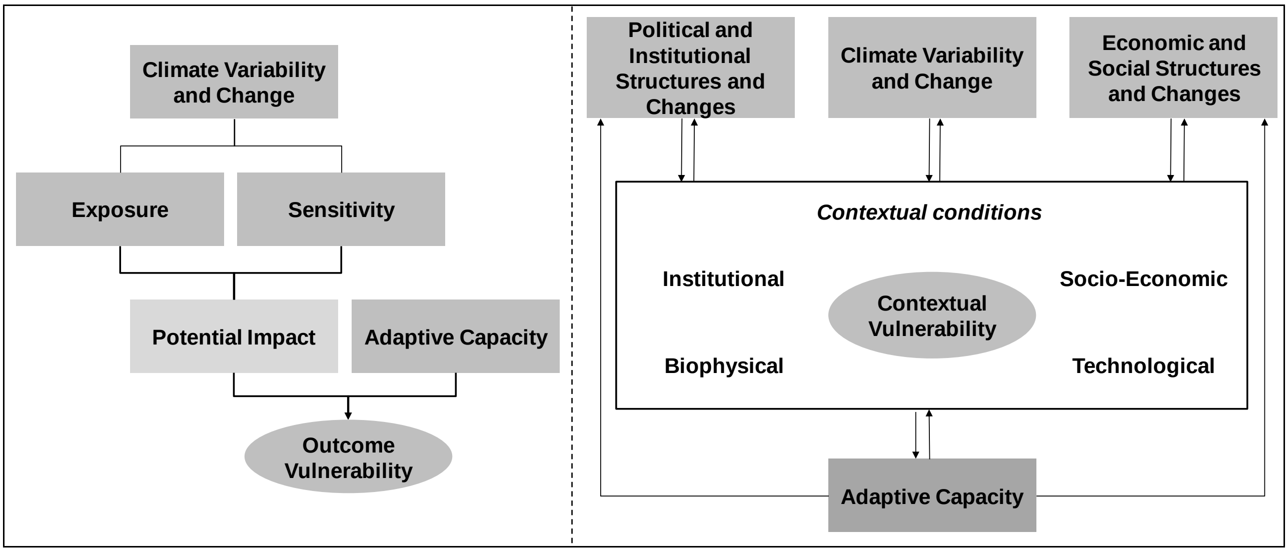
3. Alternative interpretations and concepts of vulnerability: the relative role of natural and social science

Similar to the variety of vulnerability definitions, the literature provides a vast variety of interpretations and alternative concepts of vulnerability. The concepts often originate from different academic disciplines and professional fields of practice and they often differ with regard to their unit of analysis (e.g. individual, household or region) and methods (Adger, 2006, Füssel and Klein, 2006, O'Brien et al., 2007, Pearson et al., 2009). The concept of climate change related vulnerability has been comprehensively reviewed by many authors (see e.g. Kelly and Adger, 2000, Alwang et al., 2001, Brooks, 2003, Adger, 2006, Füssel and Klein, 2006, Eakin and Luers, 2006, Eriksen and Kelly, 2007, O'Brien et al., 2007). Different concepts and interpretations of the character and cause of vulnerability produce different types of knowledge and therefore also result in different accentuations of strategies for reducing vulnerability (Kelly and Adger, 2000, Füssel et al., 2007, O'Brian et al., 2007, Maru et al., 2011). Moreover, the broad characteristics of

[2] It has to be noted that while the critical threshold in figure 3 is held constant, in the real world coping ranges are not necessarily fixed over time and can dynamically respond to internal processes in addition to external climatic and non-climatic drivers (Yohe and Tol, 2002, Jones and Boer, 2005, Smit and Wandel, 2006, Carter et al., 2007).

alternative vulnerability interpretations can be quite confusing, and even more so in the climate change area, where researcher and stakeholders with different background knowledge collaborate. Therefore it is not only beneficial but important to identify the thinking behind specific vulnerability analyses and to highlight the major differences in alternative vulnerability interpretations (Eakin and Luers, 2006, Janssen and Ostrom, 2006). Two of the most prominent vulnerability concepts in the context of climate change are outcome and contextual vulnerability, which differ mainly due to their interpretation of vulnerability as being the end-point or the starting point of the analysis. Both concepts are graphically represented in Figure 4.

Figure 4: Outcome and contextual vulnerability



Source: adjusted from Allen Consulting (2005, p.20) and O’Brian (2007, p.75).[3]

Outcome vulnerability (also known as the *“end-point" interpretation*) is a concept that considers vulnerability as the (potential) net impacts of climate change on a specific exposure unit (which can be biophysical or social) after feasible adaptations are taken into account. Thus, the outcome approach combines information on potential biophysical climate impacts with information on the socio-economic capacity to cope and adapt (Kelly and Adger, 2000, Füssel et al., 2007, O’Brian et al., 2007).

Based on natural science and *future* climate change model scenarios, outcome vulnerability approaches typically focus on biophysical changes in closed or at least well-defined systems. The boundaries between “nature” and “society” are quite firmly drawn and vulnerability is an outcome that can be quantified and measured. The outcome vulnerability is determined by the adaptive capacity of a system. However, regarding the adaptive capacity most emphasis is given to biophysical components and the role of socio-economic components in modifying the effects of climate change is rather marginalized. Accordingly, the most vulnerable systems are considered to be those that will undergo the most dramatic physical changes.

Studies that follow an outcome approach typically focus on technological solutions for adaptation and mitigation strategies to minimize particular impacts of climate change (Brooks, 2003, Eriksen and Kelly, 2007, Füssel et al., 2007, O’Brian et al., 2007). Studies that focus for example on the vulnerability of agricultural yields to climate change in the future tend to follow an outcome vulnerability approach and

[3] Note: The IPCC definition of vulnerability to climate change as presented in figure 2 corresponds to outcome vulnerability (left part of figure 5).

typical technological solutions for adaptation in the agricultural sector include e.g. the use of different crop seeds, production techniques or water management (Tubiello and Rosenzweig, 2008, Challinor et al., 2009, Peltonen-Sainio, 2012).

Contextual vulnerability (also known as the *"starting point" interpretation*) is a concept that considers vulnerability as the present inability of a system to cope with changing climate conditions, whereby vulnerability is seen to be influenced by changing biophysical conditions as well as dynamic social, economic, political, institutional and technological structures and processes. Thus in the contextual approach, vulnerability is seen as a characteristic of ecological and social systems that is determined by multiple factors and processes (Adger, 2006, O'Brian et al., 2007).

Based on social science, contextual vulnerability approaches typically focus more on the *current* socio-economic determinants or drivers of vulnerability, i.e. social, economic and institutional conditions. Specific determinants that can increase or decrease a system's vulnerability include for example marginalization, inequity, food and resource entitlements, presence and strength of institutions, economics and politics (Adger and Kelly, 1999, O'Brien and Leichenko, 2000, O'Brian et al., 2004, Cardona et al., 2012). Thus the contextual interpretation of vulnerability explicitly recognises that vulnerability to climate change is not only a result of biophysical events alone but is also influenced by the contextual socio-economic conditions in which climate change occurs. Nature and society are usually seen as joint aspects of the same context, i.e. a strong human-environment interrelation is assumed and the boundaries between nature and society are not firmly drawn. The current vulnerability to climatic stimuli determines the adaptive capacity of a system, and climate change modifies the biophysical conditions but also the context in which climate change occurs.

The contextual approach builds on the dual consideration of socio-economic and biophysical aspects that make a system vulnerable (Luers et al., 2003, O'Brien et al., 2004, Polsky et al., 2007). The general concept of socio-economic vulnerability is illustrated in Schröter et al. (2005) with an example on famine. Schröter et al. (2005) argue that rather than focusing on the physical stress (e.g. drought) as cause of famine, it might be more informative to focus on the social, economic and political marginalisation of the individuals or groups as the cause for that famine. Likewise, the contextual approach emphasizes that the social and ecological context in which climate change occurs is likely to be as important as the climatic shock itself (Bohle et al., 1994, Handmer et al., 1999, Turner et al., 2003, Ericksen, 2008). This observation has been confirmed by quantitative research on agricultural production, such as quantitative work on the socio-economic factors that make grain harvests in China sensitive to rainfall anomalies (Fraser et al., 2008, Simelton et al., 2009). Liverman (1990) demonstrated that different crop yields during drought periods in Mexico could not be solely explained by different precipitation patterns but were strongly influenced by different land tenure and the historical biases of farmers' access to productive resources. Likewise, Vásquez-Léon et al. (2003) illustrated how differences in access to resources, state involvement, class and ethnicity result in significantly different vulnerabilities of farmers within a similar biophysical context. In an example for North America, Mendelson (2007) finds that about 39% of the variations in average crop failure rates across the USA can be explained by variations in soils and climate, which basically implies that other factors like management skills, socio-economic, institutional and political conditions, account for the remaining 61%.

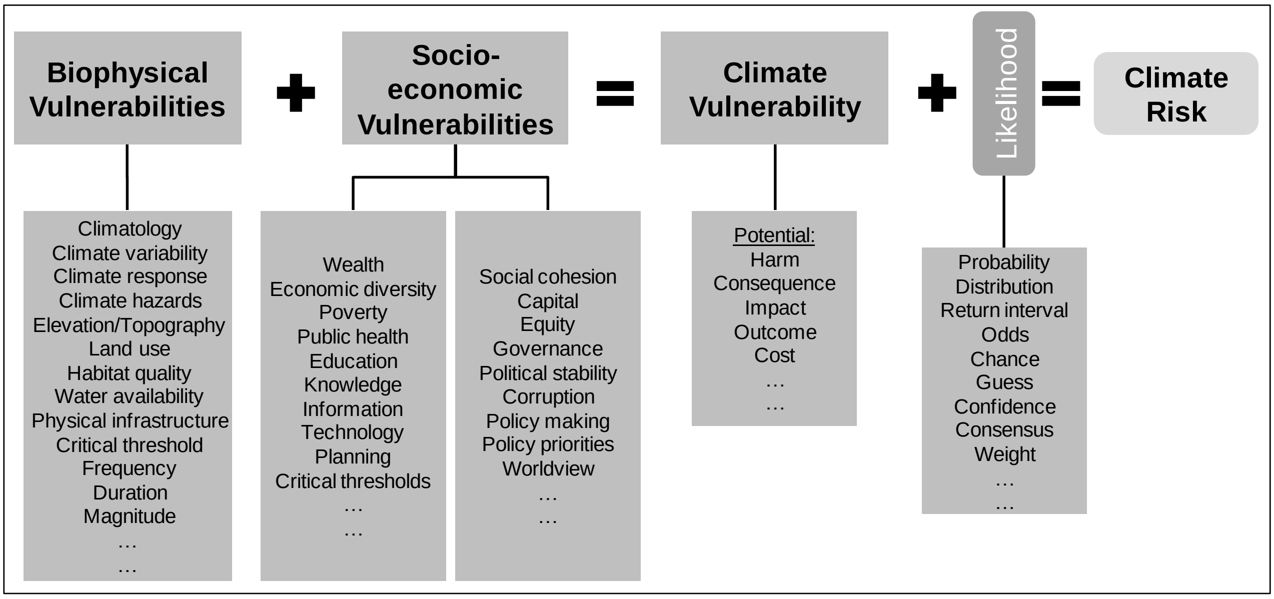
From the contextual interpretation, vulnerability can be reduced by modifying the contextual conditions in which climate change occurs so that individuals and groups are enabled to better adapt to changing climatic stimuli (Adger, 2006, Eakin and Luers, 2006, Eriksen and Kelly, 2007, O'Brian et al., 2007, Cardona et al., 2012). Accordingly, studies that follow a contextual approach typically focus on sustainable development strategies that increase the response and adaptive capacity of human populations to deal with climate change related vulnerabilities (thereby addressing the need for adaptation policy and of broader social development). An important feature of contextual approaches is typically the involvement of the population and stakeholders of the system in identifying climate change stresses, impacts and adaptive strategies.

The alternative concepts and interpretations of vulnerability reflect the fact that vulnerability is context and purpose specific, and also specific to place and time as well as to the perspective of those assessing it (cf. Adger, 2006, Füssel and Klein, 2006, O'Brien et al., 2007, Pearson et al., 2009, IPCC, 2012). In practical terms, the question on 'who is vulnerable to climate change?' can be addressed within both vulnerability approaches, with studies on outcome vulnerability focusing usually on vocations or professions, whereas contextual vulnerability focuses more on class, race, age or gender (O'Brian et al., 2007). Outcome vulnerability approaches are also often associated with questions like 'what are the expected net impacts of climate change in different regions?' or 'which sector is more vulnerable to climate change?'. However, answering these question may also form an important part of contextual approaches, especially if the economy of a society is dominated by activities that are sensitive to climate change (e.g. if the agricultural sector plays a vital role in a society's economy). Thus, the question 'why are some regions or social groups more vulnerable than others?' is closely related to contextual approaches (O'Brian et al., 2007).

As vulnerability is context and purpose specific, none of the vulnerability concepts can be considered as being better or worse than the other. As highlighted in O'Brian et al. (2007), the outcome and contextual interpretations of vulnerability should be recognized as being two complementary approaches to the climate change issue. The two approaches assess vulnerability from different perspectives and they are both important to understand the relevance of climate change and respective responses (Kelly and Adger, 2000, Adger, 2006, O'Brian et al., 2007). Moreover, in recognizing that any complex system commonly involves multiple variables (physical, environmental, social, cultural, and economic), it seems imperative to assess the vulnerability of a system by using an integrated or multidimensional approach in order to capture and understand the complete picture of vulnerability in the context of climate change (Cardona et al., 2012).

In summary and as delineated above, climate vulnerability is characterized as a function of both biophysical and socio-economic vulnerabilities, with each defined by the three dimensions of exposure, sensitivity and adaptive capacity. When combined with specific likelihood of occurrence (either associated with biophysical changes or socio-economic variables), climate vulnerability becomes climate risk (Preston and Stafford-Smith, 2009). The relationship among different concepts associated with climate change vulnerability and risk are graphically depicted in figure 5.

Figure 5: Relationship among different concepts associated with climate vulnerability and risk



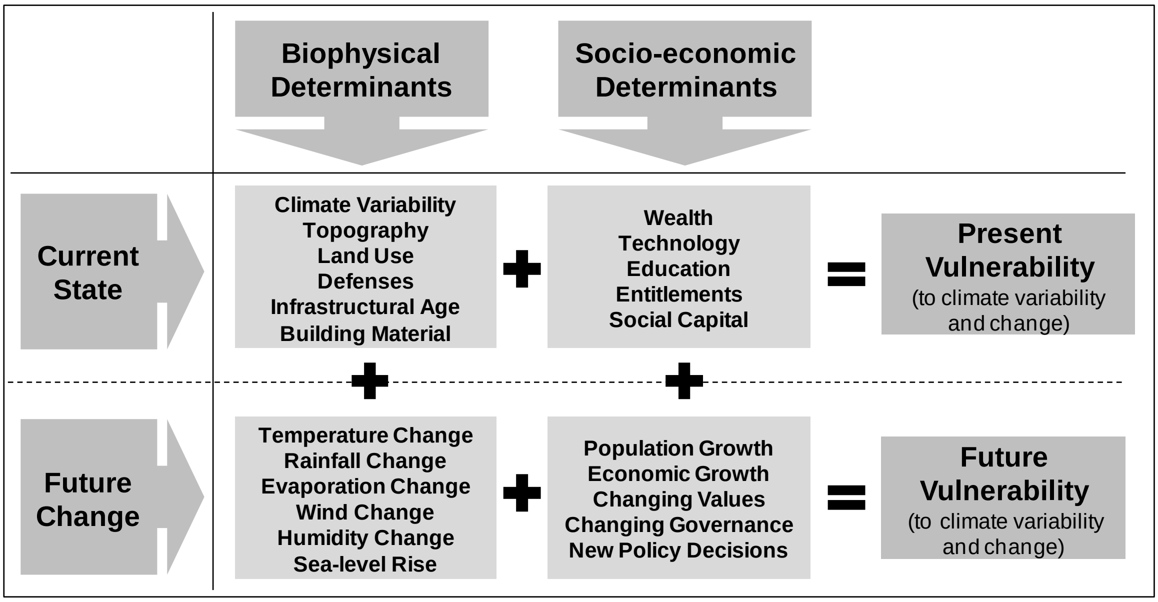
Source: modified from Preston and Stafford-Smith (2009, p.11)

4. The time dimension: further characterisation of current and future vulnerability

The discussion on alternative interpretations of vulnerability highlights that there are two different temporal references (time horizons) for assessing vulnerability. While the conceptualisation of outcome vulnerability focuses on future vulnerability, contextual vulnerability focuses on current vulnerability. This distinction can mostly be attributed to the different disciplines that are involved in research on vulnerability and adaptation (Preston and Stafford-Smith, 2009, cf. section 3). As described above, natural scientists usually focus on biophysical determinants of climate change and thus assess future vulnerability as the end-point of the analysis. On the other hand, scientists focusing on socio-economic determinants tend to focus on current vulnerability as starting-point of the analysis.

Preston and Stafford-Smith (2009) point out that both timeframes are important and valid and that it may be useful to maintain these different perspectives. However, non-climatic (socio-economic) factors can strongly modify the climatic impacts of climate change (Carter et al., 2007, Polsky et al., 2007), which implies that future vulnerability also critically depends on present (autonomous and/or planned) adaptation processes (Downing and Patwardhan, 2005, Carter et al., 2007, Carter and Mäkinen, 2011). Consequently, to obtain a complete picture of vulnerability it seems necessary to combine both the two time horizons (current and future) and biophysical and socio-economic vulnerability determinants. Preston and Stafford-Smith (2009) depict the relationship between current and future vulnerability to climate change in a diagram, with both temporal references comprising biophysical as well as socio-economic determinants (cf. Figure 6).

Figure 6: Relationships between current and future determinants of vulnerability to climate variability and change



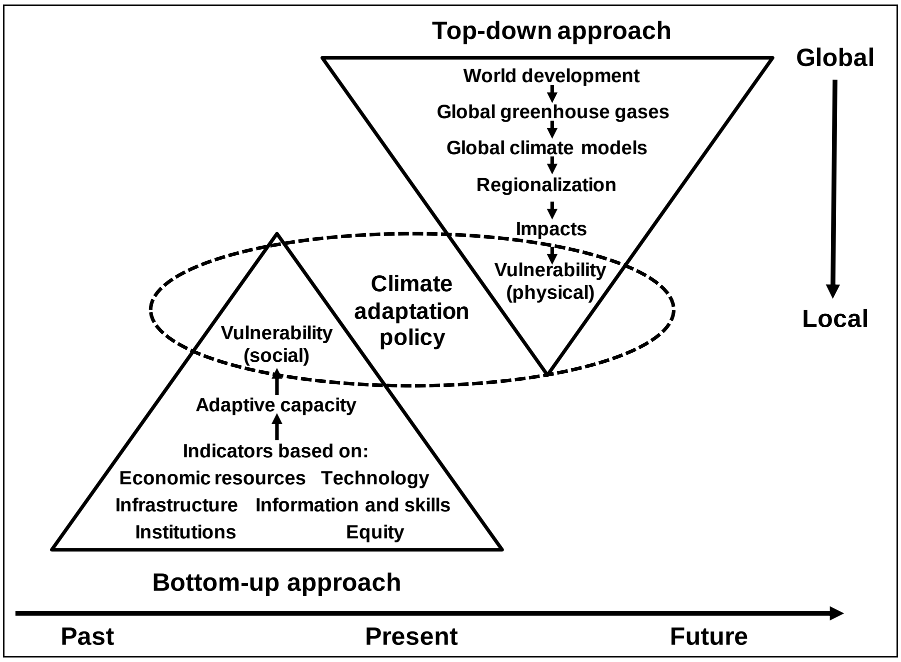
Source: slightly modified from Preston and Stafford-Smith (2009, p.18)

5. Methods for assessing vulnerability to climate change

The diversity of interpretations and concepts of vulnerability results in a variety of methodological approaches and tools that have evolved to assess it; which is also reflected in a vast variety of conducted vulnerability assessments with regard to the agricultural sector. Climate change vulnerability assessments can for example vary with respect to the methodological approach (e.g., experimental, modelling, meta-analysis, survey based), the integration of natural and social science, policy focus, time horizon (short- to long-term), spatial scale (farm, local, national, regional, global level), consideration of uncertainties, and the degree of stakeholder involvement. In this section general methods applied for assessing vulnerability to climate change are highlighted, focusing briefly on the use of indicators, modelling approaches and stakeholder involvement. Thus, the methods outlined in these sections are illustrative rather than exhaustive.

The methods used in vulnerability assessments tend to be closely related to the concept and interpretation of vulnerability. In line with the outcome and contextual interpretations of vulnerability, Dessai and Hulme (2004) highlight the different approaches the two concepts take (without explicitly referring to them) to inform climate adaptation policy. Figure 7 illustrates that outcome vulnerability concepts that concentrate on physical vulnerability tend to follow a top-down approach to inform climate adaptation policy, whereas contextual vulnerability concepts that concentrate on socio-economic vulnerability follow a bottom-up approach (Dessai and Hulme, 2004, cf. IPCC-TGICA, 2007). A top-down approach typically proceeds from global climate projections, which can be downscaled and applied to assess regional impacts of climate change. An important feature of bottom-up approaches is typically the involvement of the population and stakeholders of the system in identifying climate change stresses, impacts and adaptive strategies.

Figure 7: Top-down and bottom-up approaches to inform climate adaptation policy



Source: Dessau and Hulme (2004, p.112)

Vulnerability indicators and indices: to be used with caution

A common method to quantify vulnerability to climate change is by using a set or composite of proxy indicators. Indicators can for example be used to link biophysical and economic attributes of systems to vulnerability outcomes via a quantitative function (e.g. decline in yield, resource quality, land value or economic returns). However, identifying and constructing appropriate indicators for vulnerability assessments is highly challenging (Downing et al., 2001, OECD, 2008). Following the IPCC definition of vulnerability to climate change, measures of vulnerability typically include the three components of climate change, i.e. exposure to climate change, sensitivity to its effects and adaptive capacity to cope with the effects. Vulnerability assessments therefore typically attempt to quantify the three components by identifying appropriate indicators and combine them into indices for each. Subsequently the components are then often combined into an integrated index of vulnerability. The indicators used for the components include usually both biophysical (primarily for exposure and sensitivity) and socio-economic (mainly for adaptive capacity) sources (Yohe and Tol, 2002, Adger et al., 2004, Schröter et al., 2005, Metzger, 2005, Eakin et al., 2006, cf. Iglesias et al., 2011).

Impacts of climate variability and change can generally be described quantitatively by changes in biophysical indicators (e.g. agricultural productivity with regard to crop yields) or by socio-economic indicators (e.g. agricultural income from crop production). However, while there are agreed indicators to measure the *impact* of climate change, there seem to exist no agreed metrics to describe *vulnerability* (e.g. of crop yields or agricultural income). This seems to be the case because vulnerability is rather a relative measure than something that can be expressed in absolute terms (Adger, 2006, Füssel and Klein, 2006, Eriksen and Kelly, 2007, Füssel, 2009, Hinkel, 2011). Consequently it is argued, that i) an indicator can generally only describe a measure of relative vulnerability (between places or time periods) and ii) individual indicators are not able to portray the heterogeneity of vulnerability (especially with regard to socio-economic vulnerability). Hinkel (2011) therefore argues that a "one size fits all" vulnerability label is not sufficient as it disguises the vast amount of different types of problems addressed and methods applied. Thus rather than using the term vulnerability as an unspecific proxy it is important to use an explicit terminology in order to clarify which particular vulnerability problems are addressed and which methodologies are applied (Füssel, 2009, Klein, 2009, Hinkel, 2011).

As discussed in previous sections, vulnerability is place-based and context specific and consequently the significance of particular indicators can vary from region to region, especially depending on the specific socio-economic context. Consequently, at local scales and when systems can be narrowly defined, vulnerability indicators are considered to be a suitable means to identify particularly vulnerable people, regions or sectors (Barnett et al., 2008, Hinkel, 2011). Conversely, attempts to rank and compare vulnerability across regions or countries via indicator values, mainly with the aim to assist governmental bodies or organizations in the allocation of resources to reduce vulnerability, are often criticised. The criticism of ranking and comparing vulnerability across countries arises mainly because vulnerability is place and context specific, but also because of challenges due to quality and availability of data, the selection and creation of appropriate indicators, underlying assumptions in weighting variables, and the interpretation of indices. Moreover, the dynamic nature of vulnerability would actually require a constant updating of such vulnerability scores (Cutter et al., 2003, Eakin and Luers, 2006, Füssel, 2009, Klein, 2009, Hinkel, 2011).

Model based vulnerability and impact assessments

Research of climate change related vulnerability and impact in the agricultural sector mainly focuses still on biophysical productivity. Most of the models used follow reductionist approaches, focusing on a single or well defined group of hazards or drivers of change. Biophysical model approaches typically following a dose-response logic, focus on biophysical processes and are limited in the integration of contextual issues. Thus these model approaches have limited capacity to model adaptation options (however some rather predefined contextual adaption can be considered). Pure biophysical model approaches can range in their complexity, from using only one single climate variable and one single response to the incorporation of many processes that are considered as being important in determining system responses (e.g. dynamic vegetation models). Biophysical model approaches in the agricultural sector can assess for example the suitability of specific crops due to change in climate (e.g. Peltonen-Sainio et al., 2009), and can be used to forecast (e.g. Olesen et al., 2007) or simulate (e.g. Palosuo et al., 2011) changes in yields.

A common approach to model socio-economic vulnerability and impacts is to combine biophysical models (or their outcome) with economic simulation models in order to assess impacts of climate change on agricultural productivity and related costs of adaptation (see e.g. Nelson et al. 2009, Reidsma et al., 2010). An alternative to such simulation approaches are statistical approaches. Statistical approaches can for example be applied to estimate statistical relationships between crop yields, temperature and precipitation (see e.g. Schlenker and Lobell, 2010). Statistical studies can also be based on cross-sectional data or time series data. In general, statistical approaches have the advantage that they require less data than simulation models. However, statistical approaches rely on predicting future responses based on past relationships (i.e.

issues like for example changes in varieties grown are not taken into account), i.e. no adaptation responses are considered. In contrast, adaptation responses are somehow considered in Ricardian approaches. Ricardian approaches recognise that farmers will vary their mix of activities (to yield the highest return on their land) and therefore they focus on the impact of climate change on land values instead of yields. Thus, in Ricardian approaches climatic variations are associated with variations in land values in order to estimate the economic impact of changes in climate once adaptation has taken place. Critique on Ricardian approaches arises because they rely on the assumptions that there is a long run equilibrium in factor markets (especially land) and that there are no adjustment costs. Furthermore they are comparative static, i.e. dynamics of adjustments are not considered (see e.g. Mendelson et al., 2007, Mendelson, 2008, Lippert et al., 2009).

Stakeholder involvement

Especially at local and national scale, the application of vulnerability assessments methods allows interaction with stakeholders. The involvement of stakeholders can take place at several stages of an assessment to agree upon the main issues and responses in assessing vulnerability to climate change. Participatory methods are applied in order to obtain first-hand documentation of vulnerability due to social conditions and physical stimuli from the perspectives of community members. Furthermore, when quantitative data is not available, expert opinion of regional stakeholders can offer alternative sources of information. In addition, stakeholders can also provide valuable information on non-climatic stimuli that may be important for mitigating climate change impacts (Downing and Ziervogel, 2004, Salter et al., 2010, Malone and Engle, 2011).

There are various methods to involve stakeholders, including cognitive mapping, expert judgement, brainstorming or checklists, but also via interviews or surveys (for brief descriptions see Downing and Ziervogel, 2004). Participatory stakeholder methods can generally help to produce results that are more acceptable to stakeholders and therefore also more implementable. The involvement of stakeholders is considered as being particularly crucial in identifying and planning the most appropriate forms of adaptation (which will then also contribute to a successful implementing of adaptation policies). The level of stakeholder involvement can vary from passive engagement (providing information through meetings or interviews) to self-mobilization (initiating and designing processes). Generally, stakeholder involvement can be used as the main method for vulnerability and adaptation assessments as well as in combination with other methods (Downing and Ziervogel, 2004, Salter et al., 2010, Malone and Engle, 2011).

As highlighted in the previous sections of this paper, vulnerability is context and purpose specific and hence the answer to the question which vulnerability assessment approach for the agricultural sector, production system and/or region is most appropriate, depends on multiple aspects, among others the specific research or policy questions to be addressed, the geographical and temporal scope of the analysis, and the availability of data, expertise, and other resources.

6. Data constraints and treatment of uncertainties

Questions related to the availability, quality and application of information and data as well as related uncertainties are important and should be addressed in any vulnerability assessment. There is vast literature on the use of data and scenarios in climate change impact and vulnerability assessments (e.g. Carter et al., 2007, IPCC-TGICA, 2007, Rounsevel and Metzger, 2010) and for example the Data Distribution Centre (DDC) of the IPCC provides climate, socio-economic and environmental data, along with technical guidelines on the selection and use of different types of data and scenarios (IPCC-DCC, 2012).

Climate change impact and vulnerability assessments apparently contain a certain level of uncertainty and it is necessary to document and communicate the uncertainties associated with the choice and availability of data, the approach taken and the results of the assessment (IAC, 2010, Mastrandrea et al., 2010, Jones and Preston, 2011). Moss and Schneider (2000) highlight several examples of sources of uncertainties, comprising (i) problems with data (e.g. missing, errors, noise, random sampling error and biases), (ii) problems with models (e.g. structure, parameters, their credibility over time, predictability of the system or effect, approximation techniques) and (iii) other sources of uncertainty (e.g. ambiguous definitions of concepts and terminology, inappropriate spatial/temporal units, underlying assumptions, human behaviour in the future).

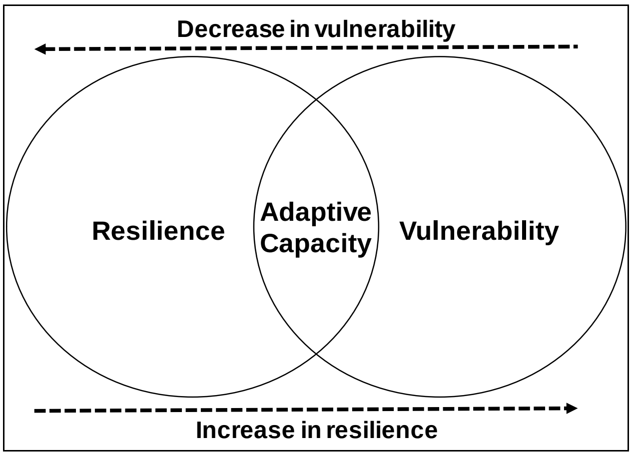
Some categories of uncertainty are possible to quantify, while others cannot be sensibly expressed in terms of probabilities. In the guidelines for the fifth assessment report of the IPCC, two metrics for the communication of the degree of certainty are proposed, with one metric comprising quantified measures of uncertainty in a finding that can be expressed probabilistically (based on statistical analysis of observations or model results, or expert judgment). The other metric for the degree of certainty is expressed qualitatively and comprises confidence in the validity of a finding, based on the type, amount, quality, and consistency of evidence (e.g. mechanistic understanding, theory, data, models, expert judgment) and the degree of agreement (Mastrandrea et al., 2010).

In any vulnerability assessment the data and methods applied to characterize the past, present and future in the assessment (e.g. for climate, other environmental, land use, socioeconomic and technological conditions) should be clearly stated. Likewise, it has to be communicated which parts of the assessment are based on observations, on models and on future scenarios. Data constraints (e.g. availability, quality, applicability) need to be indicated and for the communication of uncertainties in a vulnerability analysis it is useful that the most important factors and uncertainties that are likely to affect the conclusions are identified for each of the major findings (Moss and Schneider, 2000, Swart et al., 2009, Mastrandrea et al., 2010).

7. Concluding remarks and framework table for climate change related vulnerability assessments

The OECD and the FAO are working together on an analytical report that focuses on building resilience in agricultural production systems in the context of climate change. In the context of the report, the purpose of this paper is to provide a review of conceptual frameworks for the assessment of climate change related vulnerability, highlight major differences in alternative vulnerability interpretations and give some reference examples for the agricultural sector. In the literature many authors recognise the potential linkage between vulnerability and resilience (e.g. Turner et al., 2003, Eakin and Luers, 2006, Gallopin, 2006, Young et al., 2006, Nelson et al., 2007, Polsky et al., 2007, Vogel et al., 2007, Cutter et al., 2008, Turner, 2010, Engle, 2011). Even though vulnerability and resilience can be seen as separate concepts, they are linked through the concept of adaptive capacity (Engle, 2011, cf. figure 8) and greater emphasis from a combined perspective can help to assess adaptive capacity (Engle, 2011).

Figure 8: Vulnerability and resilience frameworks as linked through the concept of adaptive capacity



Source: adjusted from Engle (2011, p.252)

Assessments in the climate change area are usually characterized by collaboration of researchers and stakeholders with different backgrounds and knowledge. Different interpretations of the character and cause of vulnerability can result in different accentuations of strategies for reducing vulnerability. Therefore it is important to identify the thinking behind specific vulnerability concepts and highlight the major differences in alternative vulnerability interpretations. Two of the most prominent vulnerability concepts in the context of climate change are outcome (end-point) and contextual (starting-point) vulnerability. The main features and differences between the outcome and contextual vulnerability approaches of vulnerability are summarized in Table 1.

Table 1: Alternative concepts and interpretations of vulnerability in climate change research

	Outcome vulnerability (end-point interpretation)	**Contextual vulnerability** (starting-point interpretation)
Root problem	Climate change	Socio-economic vulnerability
System of interest	Biophysical, closed or at least well-defined systems	Human security or livelihood interrogation
Main discipline	Natural science	Social science
Analytical function	Descriptive, positive	Exploratory, normative
Starting point of analysis	Scenarios of future climate change	Current vulnerability to climatic stimuli
Vulnerability and adaptive capacity	Adaptive capacity determines vulnerability	Vulnerability determines adaptive capacity
Reference for adaptive capacity	Adaptation to future climate change	Adaptation to current climate variability
Meaning of vulnerability	Expected net damage for a given level of global climate change	Susceptibility to climate change and variability as determined by socioeconomic factors
Illustrative research question	What are the expected net impacts of climate change in different regions?	Why are some groups more affected by climatic hazards than others? Who is vulnerable to climate change and why?
Policy context	Climate change mitigation, compensation, technical adaptation	Social adaptation, sustainable development
Illustrative policy question	What are the benefits of climate change mitigation?	How can the vulnerability of societies to climatic hazards be reduced?
Focus of results	Technologically focused on adaptation and mitigation strategies	Socially focused on increasing adaptive capacity, exploring alternative development pathways, addressing power or equity issues and constraints to respond
Approach used to inform adaptation policy	Top-down approach	Bottom-up approach
Spatial domain	Global -> local	Local -> regional
Time dimension	Future vulnerability	Current vulnerability

Source: modified from Füssel (2007, p.163) and Pearson (2008, p.8)

While both concepts define the vulnerability of a system to climate change as a function of exposure, sensitivity and adaptive capacity of the system, the major differences are mainly attributable to the relative role of natural and social science within the outcome and contextual concepts. Outcome approaches are usually based on natural science and focus on future biophysical changes. Regarding adaptive capacity most emphasis is given to biophysical components and the role of socio-economic components in modifying the effects of climate change is rather marginalized. In contrast, contextual approaches are based on social science and consider vulnerability as the present inability of a system to cope with changing climate conditions. Contextual vulnerability approaches typically focus more on the current socio-economic determinants or drivers of vulnerability, i.e. social, economic and institutional conditions.

The alternative concepts of vulnerability reflect the fact that vulnerability is context and purpose specific, and also specific to place and time as well as to the perspective of those assessing it. The outcome and contextual concepts of vulnerability should be recognized as being two complementary approaches to the climate change issue, assessing vulnerability from different perspective and both being important to understand the relevance of climate change and respective responses. Moreover, as any complex system commonly involves multiple variables (physical, environmental, social, cultural, and economic) it seems important to assess the vulnerability of a system by using an integrated or multidimensional approach in order to capture and understand the complete picture of vulnerability in the context of climate change.

Similarly to the alternative concepts of vulnerability the answer to the question which vulnerability assessment approach for the agricultural sector, production system and/or region is most appropriate depends on multiple aspects. Among these are specific research or policy questions to be addressed, the geographical and temporal scope of the analysis, and the availability of data, expertise, and other resources. In general, vulnerability assessments should help to identify the impacts of climate change at sectoral, global, national or local level and help to raise awareness and identify key issues. Thus, an assessment of agricultural vulnerability to climate change should help to identify particularly vulnerable regions and agricultural production systems. This should then result in recommendations of specific adaptation measures and also help to prioritize resource allocation for adaptation. Accordingly, vulnerability assessments should be aimed at informing affected stakeholders (farmers, policy makers etc.) and the development of response options (adaptation techniques, policies, etc.) that reduce risks associated with climate change.

To operationalize the issues outlined in this paper, table 2 presents a framework table[4], including the main elements that are considered relevant for the assessments of climate change related vulnerability in the agricultural sector. The framework table could be a useful reference for those actually doing the vulnerability assessment, as well as for stakeholders, policy makers and further users of the respective vulnerability analysis. The table can be helpful in presenting main elements of a vulnerability analysis by reducing complexity and thus easing comparison, understanding and communication of approaches and results of vulnerability assessments.

[4] The table is adapted from a proposed framework presented by Carter and Mäkinen (2011).

Table 2: Elements of a framework for climate change related vulnerability assessments in the agricultural sector

Assessment type, purpose and target audience	
Study name	Full name
Specific research questions	Indicate the specific research questions addressed by the analysis
Emphasis and approach of the assessment	Main orientation (climate risks, adaptation, global policy analysis) and main approach (vulnerability, but could be also impact, adaptation, integrated)
Target audience	The intended target audience and other potential interested parties (e.g. researchers, policy makers, affected farmers, communities, other stakeholders)
Dimensions of the assessment	
System of interest (sectoral/ thematic focus)	Thematic focus of the assessment (agricultural productivity, food security, water resources, rural livelihood, etc.). Indicate if other sectors than agriculture (specific population groups or communities, etc) are considered
Regional scope	Region(s) for which the analysis is carried out and results are valid
Spatial scale	Spatial scale of the analysis (farm, local, national, regional, global level) for which the analysis is carried out and results are valid
Temporal reference	Indicate if the focus is on current and/or future vulnerability Indicate if past, current and/or future perspectives are included in the analysis
Biophysical aspects considered	Indicate the biophysical aspects considered in the analysis
Socio-economic aspects considered	Indicate the socio-economic aspects considered in the analysis
Methods and participation	
Methods and tools	Specific analytical methods and tools applied in the assessment as well as details of their application
Involvement of stakeholders	Yes/No (in the case of yes, indicate key stakeholder groups who have formally contributed to the assessment and the format of their involvement)
Information management	
Data and scenarios	Data and methods applied to characterize the past, present and future in an assessment (e.g. for climate, other environmental, land-use, socio-economic and technological conditions)
Data constraints	Indicate data constrains (e.g. availability, quality, applicability)
Treatment of uncertainty	Sources of uncertainty (due to e.g. problems with data, models, underlying assumptions) and their treatment
Assessment outputs	
Metric(s)	Specific measures/measurements and units in terms of which results are presented (e.g. change in crop yields, farm income, or indicators)
Presentation of results	Approach for displaying and documenting results, background information, methods and conclusions to users (use of narratives, maps, charts, tables)
Documentation & publications	Peer reviewed articles, technical reports, other reports, web descriptions, etc.

Source: adapted from Carter and Mäkinen (2011)

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