A systematic review of local vulnerability to climate change: in search of transparency, coherence and comparability

Working Paper No. 97

CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

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Abstract

Because vulnerability is a conceptual construct rather than a directly observable phenomenon, most vulnerability assessments measure a set of "vulnerability indicators". In order to identify the core approaches and range of variation in the field, we conducted a systematic literature review on local vulnerability to climate change. The systematic review entailed an identification of frameworks, concepts, and operationalizations and a transparency assessment of their reporting. Three fully defined relevant frameworks of vulnerability were identified: *IPCC*, *Patterns of Smallholder Vulnerability* and *Vulnerability as Expected Poverty*. Comparative analysis found substantial heterogeneity in frameworks, concepts and operationalizations, making it impossible to identify patterns of climate vulnerability indicators and determinants that have robust empirical support. If research measuring farmers' vulnerability to climate change is to have any comparability, it needs greater conceptual coherence and empirical validity. We recommend a systematic program of testing and validating vulnerability measures before institutionalizing them in programmatic contexts.

Keywords

Vulnerability; climate change; systematic review; research methodology; evaluation methods

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Acronyms

AR3	IPCC Third Assessment Report
CCAFS	Climate Change, Agriculture and Food Security
DFID	Department for International Development (UK)
IPCC	Intergovernmental Panel on Climate Change
RCT	Randomized controlled trials
SME	Subject matter expert
VEP	Vulnerability as expected poverty

Introduction

As a global program, CCAFS (Climate Change, Agriculture and Food Security) is actively engaged in understanding farmers' vulnerability to climate change across its benchmark sites. This is in order to effectively target measures that enhance farmers' adaptive capacity and reduce their vulnerability. CCAFS aims for its research and interventions to affect real world outcomes through carefully constructed impact pathways, which represent a programmatic agenda across the four flagship programs, which are implemented in five regions in the global tropics. From a programmatic point of view, an important question emerges from these objectives: how can CCAFS assess the impact of its various activities and interventions on farmers' vulnerability to climate change? Consequently, the research presented in this working paper aims to provide the foundation for a conceptually coherent and empirically valid approach to measuring farmers' vulnerability to climate change and the way it changes over time. Looking beyond CCAFS, the research findings and recommendations can also inform other regional or global programmes on how to assess evaluation of interventions designed to reduce vulnerability and promote adaptation to climate change. The research objectives were pursued by reviewing high quality case studies of local level climate vulnerability assessments.

As vulnerability cannot be directly observed, most vulnerability assessments rely on measuring a set of "vulnerability indicators". These are the indicators linked to factors that explain how a unit of measure (person, household, community, etc.) is vulnerable to a shock and predict negative outcomes. These indicators vary depending upon the framework used, the research question at hand, the methodology employed, the context in which research is undertaken and often the disciplinary paradigm of the researchers. The cause and effect relationships between determinants and the outcomes are sometimes assumed, sometimes inferred, and occasionally rigorously explained. This diversity of approaches, which undermines comparability and complicates interpretation when dealing with vulnerability, suggested that it would be useful to undertake a systematic review to identify a suitable core set of candidate indicators to represent vulnerability at the appropriate scale required.

Different fields of research have developed their own approaches to vulnerability, often heavily influenced by their topical and disciplinary foci (Sumner and Mallett, 2013). This has created multiple frameworks for understanding vulnerability to climate change and its subsequent classification (Adger, 2006; Adger and Vincent, 2005; Eakin and Luers, 2006; Gallopín, 2006; Vincent, 2007). One key division comes between physical scientists and social scientists - the former typically defining vulnerability based on physical exposure to extreme events and their outcomes, with the latter stressing the importance of social structures and differential access to resources (Adger, 2006). There has also been some blending of these two schools of thought, where the assessment is based on both aspects of a hazard as well as the social structures that respond.

The conceptual and methodological choices made in vulnerability research are not mere technicalities. While much research is conducted on rural society and livelihoods, it can be extremely useful to closely examine the scientific practices through which that research is done (Crane, 2014; Weiler et al., 2014), because what is included and excluded in a research framework can alter findings and the socio-political and scientific responses to them. For example, while composite vulnerability indices have been popular (Brooks et al., 2005; Vincent, 2007), methodologies for developing composite indices have been under scrutiny because the indicators are generally derived from anecdotal information from case studies or expert opinion, rather than having been empirically validated (Notenbaert et al., 2013). This

practice is problematic because resulting designations, such as ‘vulnerable’ or ‘not vulnerable’, mask the uneven rigor of underlying research, the complexity of the determinants aggregated and the interactions which produce their combined influence on vulnerability. In short, while their simplicity makes them programmatically convenient, indices reveal little about the socio-ecological processes through which vulnerability is produced, thus providing little evidence-based guidance for policy or technical interventions (Eakin and Bojórquez-Tapia, 2008).

In contrast, many vulnerability assessments have focused on local or community scale, where vulnerable groups and coping strategies can be concretely identified (Stephen and Downing, 2001). Household and community level analyses allow insight into how similarly exposed populations exhibit different degrees of vulnerability (Eakin and Bojórquez-Tapia, 2008), usually due to how different sets of specific household characteristics – assets, activities and perceptions, for example – are associated with vulnerability outcomes. Local level assessments have the potential to recognize the context- and system-specific dynamics of vulnerability determinants, which change according to the hazard (Eakin and Bojórquez-Tapia, 2008). The volume, the diversity and the importance of studies of local or household vulnerability in identifying determinants justify our decision to focus on them in this project.

The dynamic process of vulnerability can be attributed to changes at a variety of inter-linked temporal and spatial scales, reflecting non-linear interactions and feedbacks that affect the vulnerability outcomes of a particular system under consideration (Downing et al., 2006). The extent to which these interactions and feedbacks are considered is a critical factor for interpreting vulnerability assessments (Adger, 2006). Following on this, it is important to note that just as vulnerability is produced by the intersection of specific contextual drivers, vulnerability assessments are themselves also often conducted at the intersection of specific contexts, actors and interests (Pronk et al., in review). The way that the science of vulnerability research is situated within policy discussions and responses is thus important. These factors can influence the resultant identification of vulnerability determinants and impacts, and thus the policy responses.

Reflecting practices common in the wider field of climate vulnerability studies, research often approaches vulnerability using select literature studies in tandem with scientific and site-specific expert opinion to summarize the vulnerability indicators for locales or sectors under consideration. In effect, a variety of approaches have been pursued. As the new set of Flagships get underway, a more in-depth assessment of vulnerability indicators was deemed necessary, especially to determine if, through critical analysis of frameworks and methodologies, evidence from local level studies could be used in monitoring and evaluation matrices at national or global scales across CCAFS target regions, and ultimately in the evaluation pathways, both for the regional programmes and Flagships.

Systematic review was selected as a methodological approach through which to distil information from the vulnerability literature. However, the rigour and transparency that make systematic review so powerful also make it a complex and highly demanding methodology. The challenges inherent in systematic review resulted in the project unfolding in two phases. The first phase (henceforth referred to as “initial review”) began with searching and identifying the literature, but ran up against substantial barriers in extracting necessary data. The initial systematic review effort encountered several difficulties that derive primarily from a lack of consistency both in reporting and in research practice, both of which were exacerbated by the complexity of the topic studied. The initial effort encountered and stumbled on the finding that heterogeneity in research on local climate vulnerability makes it impossible to justifiably compare studies using a data extraction and quality review template that takes reports of research at face value. Needing to read behind authors’ surface claims made it far more complex than initially anticipated to draw conclusions about the realities of climate vulnerability from the literature. The same heterogeneity that frustrated our work,

however, did point to the importance of identifying how vulnerability is conceived, how it is studied, how current research should be interpreted and the implications this has for future research and recommendations drawn for interventions and activities. The second phase of the research (referred to as the "current study" when necessary) brought systematic review specialists on board to substantially refine the methodological approach.

The next section of this paper briefly describes and justifies systematic review as a methodological approach to pursue the objectives of the project. The subsequent section outlines the methodology used in this study. This is followed by a results section that describes the empirical findings that have been established through the systematic review of the climate vulnerability case study literature. These are then discussed both in terms of the state of the field as well as programmatic implications for CCAFS. Recommendations are then made on how CCAFS should structure and pursue vulnerability research and monitoring and evaluation over the coming years.

Systematic Review

Systematic review is a formal research methodology for identifying, assessing, and interpreting available evidence on a chosen topic and specific research question (Thomas and Harden, 2008). The methodology has its origins in the health sciences, when in the early 1990s scholars began to develop methods for systematically analysing multiple studies of Randomized Controlled Trials (RCT) in healthcare interventions (Dixon-Woods et al., 2006; Magarey, 2001). This led to the development of a specific type of literature review termed the "systematic review", which was based on rigorous and replicable steps throughout the review process. Its rigor and replicability has lead it to be considered as a research method in own right, in contrast to traditional literature reviews (Magarey, 2001).

Systematic review typically consists of the following steps: a transparent and reproducible search strategy; selection of studies to be included in the review through the use of defined protocols; extraction of data from subject literature through data extraction instruments; and the secondary analysis of extracted data (Magarey, 2001; Wells and Littell, 2008). Each of these steps is pursued through a method that embodies the principles of rigor, transparency, reliability, and comprehensiveness.

During the past 20 years, the systematic review approach has undergone adaptation. From its origins in the health sciences it is now used increasingly in the social sciences (Evans and Benefield, 2001; Price, 2005; Secomb, 2008; Wallace et al., 2004) while in place of an exclusive concern with RCT data, methods have been developed for the systematic analysis of qualitative data (Campbell et al., 2003; Dixon-Woods et al., 2006; Major and Savin-Baden, 2012; McCullough et al., 2007; Wallace et al., 2004). Furthermore, in some cases systematic reviews have been adapted for a rigorous appraisal of *methods* rather than *data*, with the aim of generating more robust concepts, operationalizations, or measures (Dubois et al., 2013; Le Reste et al., 2013; van der Lee et al., 2007). Nevertheless, in adapting to each of these areas of application, constituent methods have been developed which remain true to the core systematic review principals of rigour, transparency, reliability, and comprehensiveness.

In the initial effort, we aimed to evaluate evidence from multiple high-quality local-level vulnerability assessments in order to identify a generalizable set of causes and drivers of local climate vulnerability. Our intent was to support the design of interventions to foster adaptation to climate change that could be assessed, evaluated and scaled out. Despite the fact that all papers claimed to be studying what they referred to as 'vulnerability', we found diverse conceptualizations of vulnerability, a commensurate array of methodologies for its assessment and a remarkable variety of purposes. The degree of conceptual and empirical heterogeneity across the studies made rigorous comparative analysis virtually impossible. Consequently, we were not able to achieve the goal of the initial study.

So, taking a step back, we undertook a second study, presented here, that drew on the commitments to and methods developed for systematic review to make explicit what was actually being researched in the various approaches to the study of local vulnerability. In essence, instead of attempting to draw realist conclusions about determinants of local level climate vulnerability, we adjusted the project to research the variety of ways that vulnerability research itself has been conducted. Consequently, the purpose for the current study is both to provide grounds for the interpretation of existing studies and to offer suggestions for future research on local vulnerability to climate change.

Despite the challenges encountered in the initial review, we chose to continue with the systematic review approach because it contributes certain benefits to the purposes of the CCAFS programme that cannot be achieved with a traditional literature review. Firstly, the heterogeneity of approaches, methods, and scales of analysis used in existing studies on vulnerability makes it difficult to determine which research methods are best. A systematic review can help clarify and stabilize different conceptualizations of 'vulnerability' and identify methodological differences that are not otherwise apparent. This can allow a more coherent choice to be made when selecting the best methods, which will help CCAFS build a stronger research design, therefore producing more authoritative results. Secondly, because the underlying heterogeneity prevents comparability between studies, disentangling the methods used in existing studies can make explicit what is actually being researched, thus allowing more valid comparison between the CCAFS research and other studies in the field. Thirdly, clarification of the concept of vulnerability can lay the groundwork for a subsequent identification of drivers, causal mechanisms, and other patterns of vulnerability, which until now remain obscured by the unacknowledged differences in approaches. Finally, a systematic review of the vulnerability literature contributes to the development of the field more broadly by aiding the standardization of research approaches, both in terms of conceptualization of 'vulnerability' and its drivers, and in terms of operationalization.

Methods

The current project builds upon the initial review. While the initial review had the same basic mandate, the work for the present review refined the research questions and the systematic review methodologies in order to deliver results that were empirically supportable. The methods described here represent a summary report on the combined efforts. For a detailed description of the methods used, see the Technical Report, published as supplementary material.

This systematic review focuses on research that has explicitly carried out some form of local level vulnerability assessment. The aim is to understand how climate vulnerability is researched in order to inform both interpretation of existing studies and to identify a robust and standard core set of vulnerability indicators for future research that supports aggregation. Understanding how the findings resulting from studies of local determinants of vulnerability can be confidently aggregated to support claims at regional and national levels has received scant attention, especially in terms of a critical appraisal of the various methodologies through which these determinants have been identified.

The focus on local level assessments in this review emerges partly from the drawbacks related to national level vulnerability indicators and their questionable reliability at the different scales and geographic contexts they claim to represent (Eakin and Bojórquez-Tapia, 2008). Finer-scale analysis at a household or community level allows greater clarity on specific causes, interactions and outcomes of vulnerability, but these studies have only rarely been explicitly informed by an interest in aggregating results at a higher level. Furthermore, if interpretable and comparable, the sheer number of published local level vulnerability assessments would provide a large pool of empirical (reported) material for aggregation into

regional or national level conclusions.

The overall research framework for our analysis of the local climate vulnerability assessment literature has been designed to answer the following core research questions.

- How is vulnerability conceptualized?
- How is vulnerability operationalized?
- Which operationalizations are empirically valid?
- Which conceptualizations are supported by sound operationalizations?

The methods used to conduct this review can be organised into six broad stages:

1. Selection of literature
2. Identification of constructs, frameworks and operationalizations
3. Synthesis of frameworks and constructs
4. Transparency assessment of operationalized constructs.
5. Validity and feasibility assessment of operationalized constructs
6. Integration of candidate operationalizations into ideal-type frameworks

Selection of literature

The literature selection for the initial review was brought forward and added to in the second review. Therefore, this section reports on two distinct stages of selection of literature. For the first review a search was carried out across 15 scientific databases (Annex 1). A separate search string was composed for each database reflecting the particular characteristics of that database (see Annex 2). Search strings were based on a common set of terms, which were derived from the central research question of the initial review[1], and then adapted to the specific databases[2]. This search of databases returned 168 papers. Initial screening for relevance was conducted on titles and abstracts of these articles.

The key eligibility criteria included:

- Rural livelihoods and households
- Sub-national unit of analysis
- Poverty
- Food insecurity
- Agriculture
- Climate change
- Climate risk
- Climate variability (includes drought and floods)
- Multiple stressors including a climate-related risk

Focus on vulnerability to non-climate factors linked to health status such as HIV/AIDS was an exclusion criteria.

Articles were included, for example, when in the context of vulnerability to climate change they referenced sub-national unit of analysis, poverty and/or insecurity. Initial screening reduced the pool of articles to 71. These 71 articles were advanced for a full text review,

[1] The research questions of the initial review were:

1. What determinants of vulnerability are common across the studies?
2. What are the causal mechanisms that link determinants and vulnerability outcomes?
3. What are the methodological approaches that give most robust and reliable results in understanding determinants and mechanisms of vulnerability?

[2] Details of this search and all other supplemental information are provided in the Systematic Review Technical Report

screening for their relevance and sufficient quality to be included in the study (see Annex 3). Screening criteria at this step included:

- Located in the global tropics
- Local level focus of assessment
- Clearly and explicit research questions
- Well articulated sampling process and data collection methods
- Empirically oriented methodology (primary or secondary)
- Description of data analysis methods
- Findings and analysis were primarily focused on vulnerability outcomes and determinants specifically, in line with our key research question and aims, rather than other topical areas such as adaptive capacity, resilience or coping mechanisms
- Draws conclusions about vulnerability indicators or determinants

After screening, 29 papers were considered to be relevant and of sufficient quality to be included in the study. 28 of these 29 articles were subsequently brought forward to the second review and constituted the initial pool of articles for the current study. The team then conducted a second stage of literature gathering based on consultation of experts in the field (Sandoval et al., 2012). It was therefore first necessary to identify and map what approaches are present in the initial pool of 28 articles. Initial analysis began with reading an article and drawing diagrams of the theoretical framework used in that paper. This same process was done with all 28 articles. These summaries of theoretical frameworks were then synthesized using a two step process. First, summaries were clustered by identifying features (e.g. scale of analysis, methodological approaches, etc.) that rendered them mutually incompatible. Summaries within each cluster were then synthesized into preliminary framework categories (c.f. Glaser, 1965 for a discussion of the constant comparative method). This analysis of the 28 articles advanced for full review identified seven preliminary frameworks, and for each category a well-executed example was chosen to as exemplar. To strengthen our ability to draw conclusions with respect to all studies of local vulnerability, we sent the result of this analysis by email to 31 selected experts in the field to ask first for examples of models and frameworks that should be added to the review (i.e. 'what are we missing'?) and secondly to nominate articles to replace those we had chosen as an exemplar.. This round of expert solicitation generated eight new suggestions. All articles were then screened for relevance, resulting in a final pool of 35 articles (Annex 4).

Identification of constructs, frameworks and operationalizations

The next stage was to more rigorously identify theoretical frameworks, constructs, and operationalizations[3] used in the final pool of papers. The 35 articles were imported into NVivo and a coding protocol was designed that would allow them to be coded evenly and transparently, and to extract data in a standardised format. This coding framework was designed based on the first two research sub-questions of the review ("how is vulnerability defined" and "how is vulnerability operationalized"). At the conceptual level, a 'theoretical framework' can be deconstructed into three components: constructs[4]; construct definitions;

[3] In this review the term 'operationalization' is used to describe any step in which a researcher moves a theoretical concept (e.g. household assets) towards an actual act of gathering data to measure or represent that concept (e.g. survey item 'how many cows do you have?). The term operationalization in this paper is used to describe both intermediary steps (household assets = cows+cribs+chickens+...) and final instrumentation (e.g. the survey item).

[4] For general purposes, throughout this document the terms 'construct', 'concept' and 'construction' are used interchangeably, although the use of the term 'construct' is preferred. In this paper a construct is any concept found in a research question. For example in the IPCC framework the construct 'vulnerability' is taken to be a function of three sub-constructs: 'exposure', 'sensitivity', and 'adaptive capacity'., each of which are further deconstructed. This disaggregation continues to the point we encounter an actual measurement (e.g. mm of rain collected in a valid measuring device).

and relationships; (following Carroll et al., 2013; Morse, 2004). These three components make the basis of the theory-coding framework. In order to code only analytically-relevant constructs (and not each and every construct mentioned in discussing theoretical approaches), the coder first identified a research question, and from there, identified constructs contained in that research question, and any additional constructs which are absolutely necessary in order to either study or make sense of that research question. Our analysis was limited by the depth of reporting in the selected articles. If a concept was named, but not defined or operationalized (which was not uncommon), it was not possible for us to interpret what the author was talking about or how they did their research. As such their report would be of no use to any organization wishing to replicate any portion of their research. As such, it was impossible for us to draw conclusions with respect to either the validity or utility of articles that had shallow reporting.

For each article, a table was created of article-specific constructs, their definitions, if provided, and if applicable the operationalization of these constructs. A standard template was created for these tables to ensure even treatment across articles. Relations between these constructs were then identified. These relationships were used later in our study to integrate operationalizations of lower-level- or sub-constructs (e.g. labour and livestock are sub-constructs of 'household assets', which in turn is a sub-construct of 'adaptive capacity') into theoretical frameworks that are defined at a higher level of abstraction. Because authors' use of language was inconsistent, we could not use author-reported constructs as a basis for identifying theoretical frameworks. For example, though many authors said they used the IPCC framework, the details of their studies often revealed limited mutual resemblance. Consequently, we used four *a priori* identified models and a miscellaneous category to code author-identified theoretical frameworks. These frameworks were *Intergovernmental Panel on Climate Change (IPCC), Vulnerability as Expected Poverty (VEP), Food Insecurity* and *Livelihoods Approach* . Graphical representations were created for each theoretical framework in each paper to provide easily digestible summaries of the frameworks. In total, 358 article-specific constructs were identified, of which 281 were defined (in some cases through reference to other works), of which 154 were directly operationalized. Twelve articles were coded as IPCC; 7 as 'Vulnerability as Expected Poverty' (VEP); 4 as Food Insecurity; 6 as Livelihoods Approach; and 19 as 'Other Framework'.

Synthesis of frameworks and constructs

The second stage of analysis opened with synthesizing the article-specific, author-reported constructs (emic constructs) into a global set of analyst-generated constructs (etic constructs) by using reported definitions and operationalizations to correct for authors' inconsistent use of language. Using these etic constructs, we then corrected our initial categorization of frameworks. For instance, we may have classified two frameworks as distinct when, in fact, their only differentiating feature was the name given by their authors to identically defined and operationalized constructs. We then generated our final set of ideal-type representations of these frameworks. Our choice to suspect and correct for inconsistent use of language allowed us to identify frameworks based not on authors' use of language but on the definitions and operationalizations. We inspected the framework clusters that were created in the first stage of analysis to generate uniform and discreet categories of frameworks. First, within each cluster, the graphic summaries of the article-specific frameworks were compared in order to tell if they were 'of a kind'. Where clusters were not assessed to be 'of a kind', codes were to be applied to enable the cluster to be split into two 'domains' (Borgatti, 1994). Once we examined articles within each a-priori specified framework, representative examples of each cluster of articles were compared in order to assess whether those clusters were distinct. Thus the frameworks identified through this method (described in detail in the Results section) are the outcome of empirical scrutiny, in contrast to standard overviews of frameworks where authors tend to report the versions of frameworks that they like the most.

After merging clusters that were found not to be distinct, our set of 26 clusters was reduced to 20.

Following the empirical identification of frameworks, the next step was to identify the key constructs that made up each framework. As our intent is to propose a common core set of indicators for studies of local climate vulnerability, we decided that it was not useful to examine and compare all of the 358 distinct constructs identified in the articles. Instead, we selected constructs that were common across all or all but one paper using each framework. As found at the level of frameworks, authors did not use terms consistently when discussing constructs. This, again, made it impossible for us to rely on terms used by authors to identify common constructs. Our solution, once again, was to make a selection of suspected equivalent constructs based on use of similar terms and later attempt to falsify our initial hypothesis of equivalence by examining their definition and operationalization. What differentiates this effort from that undertaken at the framework level is that when examining constructs at a framework level we would only trace one level of operationalization (e.g. vulnerability is a+b+c) where when examining constructs we would disaggregate as far as the report made possible (e.g. the item on a survey). All common constructs identified were listed. In doing so, all constructs with the same name were temporarily treated as one. This provided us with a total of 114 constructs. These 114 constructs were then brought forward for scrutiny. Scrutiny of constructs was done first *within* a set of constructs of the same name to test for uniformity, and secondly, *across* constructs to test for distinction

In some cases, constructs were defined by authors through reference to other articles. We recorded these references and attempted to follow references when page numbers were given but this was never the case. However, if two articles each had a construct of the same name which they referenced a common source, we concluded that they are the same construct. One hundred of the 114 constructs appeared in only one article, with the implication that they were each uniform by default. Therefore only 14 sets of construct definitions were inspected for uniformity. Of these, ten were judged to be uniform, and four were split.

After constructs that had the same name were compared within a given framework, we looked across frameworks through a cross-tab comparison. In total, 26 representative definitions were assessed to be equivalent to one or more others. Out of these 26 definitions, 7 merged constructs were created. The next step was cross-examining this set of frameworks and constructs by a team member who was a subject matter expert (SME), and then moving from author-reported constructs and frameworks (subsequently referred to as "emic") to analyst-generated constructs and frameworks ("etic"). The SME attempted to refute the hypothesis that the categorizations created through structured review was meaningful and to indicate among the frameworks found which were relevant for the purposes of the CCAFS. This inspection collapsed four frameworks into one ('Vulnerability as Expected Poverty'; 'Vulnerability as Expected food security'; 'Vulnerability as Expected Poverty – multi-level analysis'; 'Asset vulnerability (Residual)'), and merged the residual article (Mathematical formalisation of vulnerability) into the IPCC category. Fifteen frameworks were seen by the SME as relevant and five as irrelevant. The first reviewer accepted all suggestions by the SME with the exception of one suggested merger. Each resulting model is incorporated into the final set of the results (see Annex 5 and 6).

Transparency assessment of operationalized constructs

The third stage of analysis comprised testing whether authors reported how they operationalized constructs with enough detail to support interpretation, that is, was their reporting adequately transparent. Assessing whether operationalizations are transparently reported is a preliminary stage in determining if those operationalizations are empirically valid. The logic at work is that operationalizations must be interpretable before it is possible to test whether they are valid. A further issue is that if authors do not transparently report how

they conducted their research, then their research cannot be effectively interpreted or replicated. In this stage, data for adequate operationalizations is extracted from the articles, and those operationalizations that were not adequately reported were screened out.

An instrument test the transparency of reporting was designed based on that developed by Da Silva (2014), with five adaptations. First, Da Silva's instrument was developed to appraise an article as a whole, whereas the present study conducts assessment at the level of the operationalization. Therefore only a subset of the seven items in Da Silva's framework are used (Data collection methods reported; sampling strategies reported; sample sizes reported; data analysis methods reported). Secondly, an additional criterion is added to ask whether the article reports the operational questions or data collection instruments to represent the construct. Third, a criterion is added which asks whether the construct being operationalized has been defined in the paper, using the codes for construct definitions in the first stage of research. Fourth, while Da Silva lists three values for many criteria (e.g. missing; unclear; clear), here only dichotomies are used (e.g. missing or unclear; clear). One exception to this is the value 'secondary data', where allowances are made for less than full reporting when authors use an existing data source. For example, many studies used data from national weather centres to operationalize biophysical data. In such cases, full details of data collection methods and instruments were not reported in our subject articles, yet we considered them transparently reported because one could reproduce the study by approaching the same weather centre for the same data.

This assessment was carried out on 147 defined directly operationalized article-specific constructs. Of these, 113 were found to be transparent, and 34 were found to be inadequately transparent. Operationalizations that were assessed as transparent were brought forward to the next stage for validity assessment.

Assessing if operationalizations are adequate and feasible

Da Silva's transparency instrument was itself constructed around the needs of the quality assessment checklist of Kampen and Tamás (2014). However, as noted by Da Silva, it is not practical to apply the quality assessment checklist unless you have substantial knowledge of the field of research in question (2014). Therefore this stage of analysis was carried out solely by the team member with the most knowledge of the field (the SME). A validity assessment was conducted on the basis of the data collected in the transparency assessment. Two criteria, both of which must be met for validity were used:

1. The data collection methods correspond to the type of data required to represent the construct as defined.
2. The data collection methods, instruments, and analysis methods provide a complete and valid understanding of the construct defined.

In addition to validity, an assessment of feasibility was also conducted. This involved a subjective judgment by the SME about whether the operationalization of each construct was feasible within the context of the CCAFS program. This validity assessment instrument was executed on the transparently operationalized, directly operationalized, defined constructs.

Integration of candidate operationalizations into ideal-type frameworks

The final stage of analysis involves integrating those article-specific operationalizations into the ideal-type research frameworks. This stage comprised two principal tasks. First, the etic (reviewer generated) constructs in the ideal-type frameworks were matched to article-specific operationalizations using 'operational chains' based on construct relationships linking higher-order, indirectly-operationalized constructs to directly operationalized ones. Secondly, where more than one candidate operationalization was found for a given etic construct, a framework

was created which would allow a selection among them to be made by anybody with expertise in the field.

Results

Summary of Frameworks identified in review

The results of the systematic review of the papers will start by describing the theoretical frameworks that have been found and used to study vulnerability. A theoretical framework is composed of conceptual constructs and relations between these constructs. Thirty-five articles were surveyed in the review and of the 35 articles 17 frameworks were found, with 12 frameworks seen as relevant to the objective of the research (Annex 5). The analysis found three fully defined relevant frameworks: *IPCC* with variants, *Patterns of Smallholder Vulnerability* and *Vulnerability as Expected Poverty* with extensions. In this context, 'fully defined' refers to frameworks for which definitions could be found in the literature for all core constructs in the framework.

Four 'uneven' frameworks were found, namely current and *Future Vulnerability*; *Determinants of Resilience*; *Livelihood Vulnerability Index* and *Nested Vulnerability*. The label "uneven" connotes cases where there were insufficient studies in our review for us to systematically create coherent representations of them through the use of their core concepts[5].

The final group of frameworks were those defined as having insufficient definition of constructs. Five frameworks fell under this category: *Asset Vulnerability*; *Intensifying Vulnerability to Food Insecurity*; *Livelihood Trajectories,* and *Resilience and Vulnerability*; *Household Vulnerability Factors*; *Perceptions of Climate Change*. In this group of frameworks most of the core concepts were not explicitly operationalized within the article(s) reviewed. This includes cases where concepts were operationalized primarily through reference to other articles.

Fully defined relevant frameworks

IPCC

The IPCC framework is guided by the definition and theory of the IPCC, which conceives of vulnerability to climate change as having three dimensions: Exposure to climate-induced shocks (a biophysical phenomenon); the Sensitivity of the unit of analysis to such shocks (both a social and biophysical phenomenon); the Adaptive Capacity to deal with such shocks (a social phenomenon) (see Figure 1). Application of the framework often, but not always, creates a context-specific index of vulnerability from indicators of these three dimensions. Vulnerability under the IPCC framework is defined as "the degree to which a system is susceptible to, or 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 variation to which a system is exposed, its sensitivity, and its adaptive capacity" (Füssel and Klein, 2006). Articles using the framework included Antwi-Agyei (2013), Baca et

[5] It is important to note that this "uneven" label is a result of our efforts to be systematic, and not a reflection on the quality of the underlying studies. Therefore readers are advised to refer back to papers using uneven frameworks in order to get a better idea of that framework. It is also important to note that the label 'uneven' refers only to representation and not to operationalization. It is still possible for an unevenly represented framework to be fully and adequately operationalized, (e.g. 'Determinants of Resilience' and 'Livelihood Vulnerability index').

al. (2014), CARE (2009), Füssel and Klein (2006), Hahn et al. (2009), Ionesco et al. (2009), Jamir et al. (2013), Luers et al. (2003), Notenbaert et al. (2013), Piya et al. (2012).

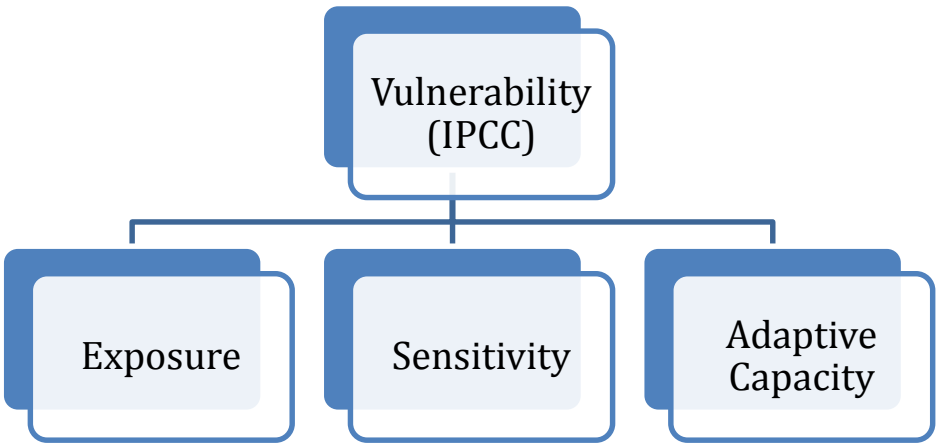

Figure 1: Key constructs of vulnerability within the IPCC framework

Patterns of Smallholder Vulnerability

The Patterns of Smallholder Vulnerability (Figure 2) framework utilises the same construct of the IPCC, but offers a substantial elaboration of smallholders' adaptive capacity, specifically on coping capacity to adjust to weather extremes, manage damages or explore alternative livelihood opportunities (Sietz et al., 2012). The framework applies the methodology of cluster pattern analysis as a way to deliver useful insights into recurrent indicator combinations based on similarities among units of analysis, in cases where such a grouping exists. The final dimension of the framework is around how vulnerability (as manifested by its three components) affect the four primary dimensions of food security: food availability, access, stability of supply and access, and utilization of food (Sietz et al., 2012).

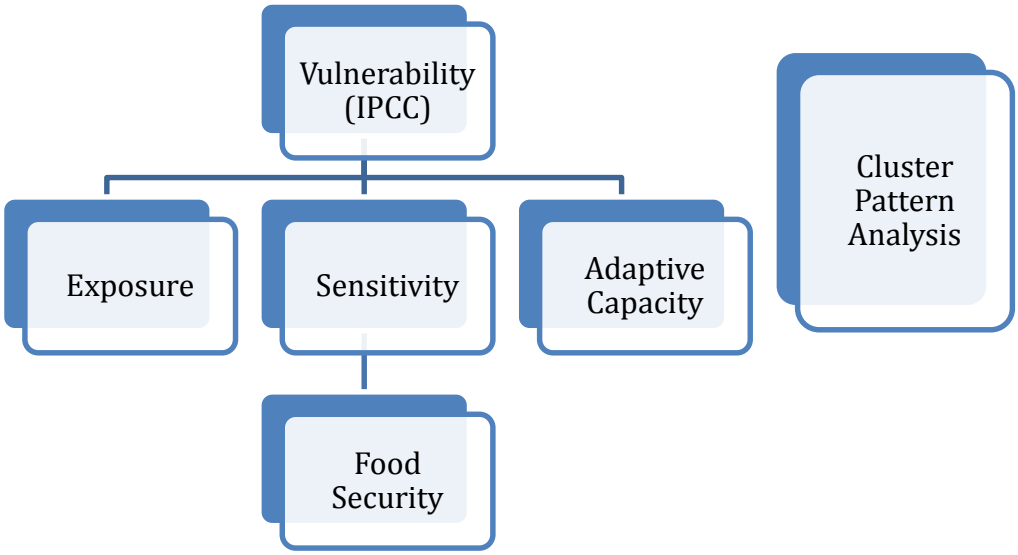

Figure 2: Patterns of Smallholder Vulnerability

Vulnerability as Expected Poverty, with extensions

The Vulnerability as Expected Poverty framework (Figure 3) conceives of vulnerability as being when the unit of analysis (usually a household) becomes or remains poor in the future. It is an econometric approach that makes forward projections based on cross-sectional data and associated risks of climatic (and sometimes non-climatic) stress. In some cases, assessments of vulnerability based on expected poverty are then regressed against a series of socio-economic data to identify determinants of vulnerability.

Extension 1: This is a variant of the framework 'Vulnerability as Expected Poverty' described above. The principal difference is that whereas the former takes its focus as that of current and projected future levels of *poverty*, usually measured through consumption, the current framework by contrast focuses on a household's current and projected future *food security* status (Capaldo et al., 2010; Mutsvangwa, 2011).

Extension 2: Another extension of the 'Vulnerability as Expected Poverty' framework described above is characterised by its inclusion of multi-level analysis. That is, projections are made for units of analysis at two different scales (usually household and community/local), and analysis is done of differences between units at different scales (Échevin, 2011; Günther and Harttgen, 2009).

The key constructs and definitions used

The framework explores the notion of vulnerability to poverty, a concept which, given socio-economic backgrounds of households, and biophysical data on expected environmental conditions, makes ex-ante estimates of a household's probability of becoming or remaining poor. Importantly this estimate is made before uncertainty regarding these conditions has been resolved. To clarify how these approaches mould together Calvo and Dercon (2013) utilized an 'axiomatic approach' to the analyse individual and clustered vulnerability. The framework integrates aspects like the household vulnerability index (Chhinh and Poch, 2012), food insecurity (Misselhorn, 2005) and expected future food security and nutritional status (Capaldo *et al*. 2010). Another important construct is around shocks, both household specific idiosyncratic shocks and covariate shocks correlated across households within communities (Günther and Harttgen, 2009), highlighting how those have different causal mechanisms and aggregate effects.

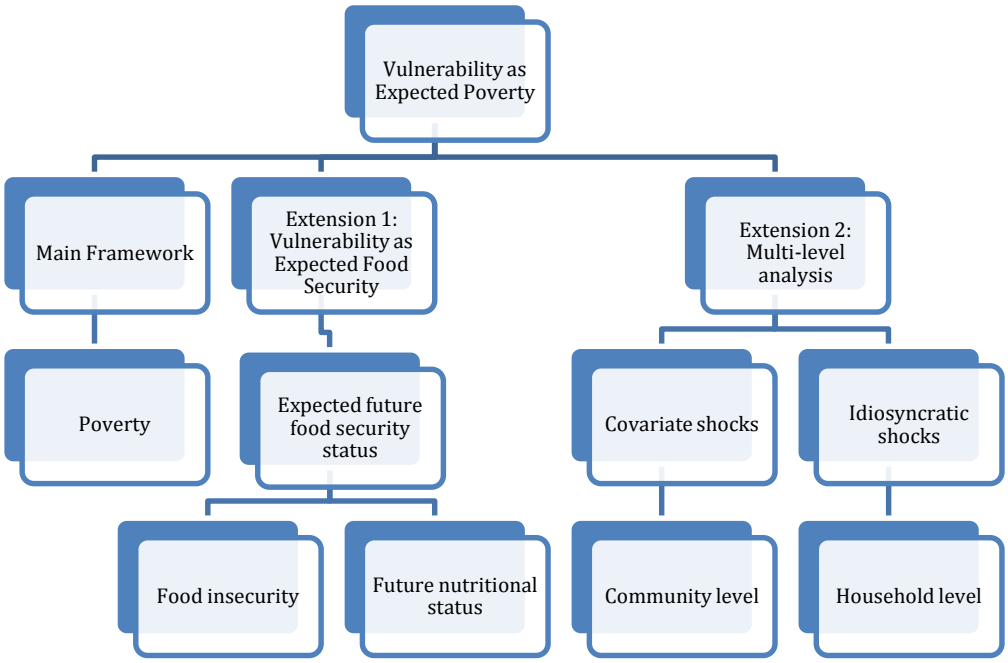

Figure 3: Vulnerability as Expected Poverty

Uneven frameworks

Current and Future Vulnerability

The main characteristics of this framework are its comparison of current and future states of vulnerability. Vulnerability is conceived as being composed of two principal elements: exposure to climatic changes, and adaptive capacity. Multiple data sources are used to generate an assessment of current exposure and current adaptive capacity. On the basis of this data, and on historical social and physical trends, projections are made as to likely future states of exposure and future states of adaptive capacity. Future exposure includes estimating the future state of socioeconomic conditions (Ford and Smit, 2004). In defining the frameworks definition of adaptive capacity it integrates the notion of 'coping range' to reflect resource options and risk management strategies. The main construct of the framework uses the model of community vulnerability to climate change, conceptualizing vulnerability as a function of exposure and adaptive capacity to deal with the exposure (Ford & Smit 2004). Importantly the framework asserts the need for communication between the climate science community and climate attributes identified by the community to assert the likelihood of changes.

Determinants of Resilience

The focus of this framework is on identifying determinants of resilience to climate-related shocks. Resilience is conceptualised temporally in terms of the time taken to make a recovery after being impacted by shocks. A vulnerability index (in this case based on the framework of the IPCC) is created to compute measures of vulnerability based on household survey data. Classifications of resilience are then created based on the time taken to return to pre-shock states, which are then analysed against the vulnerability data to identify determinants of resilient households. This framework was applied by Tesso (2012) and utilised the constructs of the DFID community resilience conceptualisations, where the management of change and

ability to transform living standards in the face of shocks and stresses whilst not compromising long-term prospects is held as a central tenant.

Livelihood Vulnerability Index

This framework consists of an index to measure levels of vulnerability. The index is composed of a highly developed set of household-level indicators chosen to represent seven dimensions of a particular conception of 'livelihoods'. These seven dimensions are: socio-demographic profile; livelihood strategies; social network; health; food; water; and natural disaster and climate change (Hahn et al., 2009).

Nested Vulnerability

This framework is concerned with 'teleconnections' between households in geographically distant localities. It examines the mechanisms through which smallholders in distinct geographical contexts respond differently to exogenous drivers and shocks (climatic or not-climatic) and in so doing create a new set of influences on distant locations through connections in a nested globally interconnected system (Eakin et al., 2009). The framework assesses response options in terms of individual or household welfare.

Relevant frameworks with insufficient definition of constructs

The following frameworks were categorized as relevant but as having not sufficiently defined constructs. Constructs were defined as insufficient if they were not found to be transparent. Constructs operationalized through reference to another article were also categorized as insufficient because time and resource constraints made it impossible for the review to request and analyse cited material. In addition, frameworks were placed in this category if the SME deemed the construct as presented in the paper to not have a valid operationalization in the frame of the central research questions of our project.

Asset Vulnerability

This framework conceives of household vulnerability to climate change in terms of the management control that can be exercised over a series of assets. These assets include labour, human capital, non-labour productive assets, household relations, and social capital. A vulnerability index is created through a framework of weighted indicators representing each type of asset. This framework was applied in the article by Dasgupta and Bashieri (2010).

Intensifying Vulnerability to Food Insecurity

Vulnerability is situated in a recursive framework, which captures a cyclical nature of intensification of vulnerability principally through the negative impacts that coping strategies can have on food security. The framework conceives vulnerability within communities as those that are unable to buffer themselves against hazards, with low ability to cope with short-term shocks and mitigate chronic stressors, which results in negative impacts on livelihoods (Misselhorn, 2005). Vulnerability is conceived principally in terms of food security, which in turn is conceived in terms of access to food and food productivity. When food security is negatively impacted through climatic and non-climatic drivers, vulnerable households and communities respond with particular coping strategies, which can have a recursive effect on future levels of food security.

Livelihood trajectories and resilience and vulnerability

On the basis of a mixed methods data collection methodology, the concept of 'livelihood trajectories' is explored among households over a time period. The framework seeks to generate narrative accounts of which livelihood strategies and trajectories lead to resilient and vulnerable states (Sallu et al., 2010).

Household Vulnerability Factors

At a very general level, this framework investigates factors affecting household vulnerability. An index is constructed through which to measure vulnerability, which is then analysed against socio-economic data to determine the most significant factors influencing levels of household vulnerability (Nkondze et al., 2013).

Perceptions of Climate Change

This category constitutes less a coherent framework and more of a collection of studies whose approach differs from the majority in this review in terms of their declared epistemological orientation and their position on the intervention cycle. The approach is explicitly subjective. It focuses on articulating perceptions of people whose livelihoods are affected by climate change (often farmers), and in particular their perceptions of climate change as a physical phenomenon, perceptions of the impact climate change has on their livelihoods, and respondent reported strategies of coping or adaptation. Key constructs of this approach centre around farmer perceptions, and the resultant adaptation and coping measures employed depend on the household's perception of extreme events and problems associated with them (Mubaya et al., 2012). The framework bases an understanding of adaptive strategies, as mediated through relative adaptive capacities and not according to the distribution of various types of resources such as physical or social capital (Westerhoff and Smit, 2008). We have chosen to include this category as relevant because it is the primary approach in which subjective experience and perception of vulnerability is acknowledged. Recognizing subjective experience as relevant made it permissible in this framework to use participatory approaches to assessment in which vulnerability can be defined through endogenous constructs of vulnerable rural populations. These endogenous constructs may be a useful addition or complement to exogenous scientific constructs and they, at minimum, are programmatically relevant as knowledge of endogenous constructs supports culturally appropriate intervention design.

Conceptualisations and constructs found across the frameworks

After coding of the final article pool, 114 constructs were identified, of which roughly 100 appear in only one article. Further scrutiny of construct definitions resulted in five frequently occurring constructs being split into nine. Although the same terminology was applied, the definitions varied markedly across the frameworks. The most significant of splits concerned the use of the term 'vulnerability' by 12 authors to denote a construct they use. After inspection, two main clusters could be detected (broadly corresponding to the IPCC definition, and the concept used in the VEP framework), in addition to some poorly defined uses of the term.

Furthermore, 26 constructs with different names were subsequently merged into seven because they used different labels to describe what were effectively the same things. For example, despite using slightly different names, we merged all of the following constructs because they used effectively equivalent definitions: 'expected poverty' (Deressa et al., 2009); 'household vulnerability as expected poverty' (Chhinh and Poch, 2012); household vulnerability to poverty' (Échevin, 2011); 'rural household vulnerability' (Sarris and Karfakis, 2010); 'vulnerability' (Calvo and Dercon, 2013; Deressa et al., 2009).

Finally, there were 37 article–specific constructs that could not be compared because definitions were not provided at all. Among those who did provide construct definitions, many were unspecific, self-referential, or otherwise difficult to work with. For example, while the IPCC-framework studies provided references to the work of the IPCC when introducing their concepts, many produced rudimentary, circular or self-referential definitions of the sub-constructs. The explanation of the concept of *exposure* given by Piya et al. (2012:11) is illustrative, although by no means unique: "Exposure is the nature and degree to which a system is exposed to significant climatic variations."

Similarly, comparison between construct definitions was made difficult by the tendency of some authors to provide more conceptual definitions and others to provide more operational definitions. That is, in defining their concepts some authors lean more towards describe the theoretical phenomenon that they are trying to represent with that concept, while others lean more towards describing what data they will use to represent the concept. For example, on the basis of Westerhoff and Smit's (2008:321) definition of *adaptation strategy* ("Adaptations, or adaptive strategies, employed by individuals or groups are depicted as being mediated through their relative adaptive capacities, indicating that adaptations may or may not be accessed according to the distribution of various types of resources such as physical or social capital") and Eakin et al's (2012:477) definition of *Impacts and responses to Hurricane Stan by coffee farmers* ("In this paper, we document household responses to a climatic shock, Stan, to gain insight into how natural resource- dependent communities move to secure their livelihoods following significant loss, the implications of household responses for coffee farming as a 'domain of attraction,' as well as to highlight those aspects of household choices and perceptions that may be indicative of resilience at broader scales."), the two constructs were assessed to be equivalent and merged. Although definitions were provided in both cases, the different formats, levels of detail, and different orientations made the comparison between them, the decision to merge, and the subsequent cross-check in the team, quite difficult. A final set of core constructs and definitions is provided in Annex 6.

Operationalizing frameworks, key concepts and indicators

Given the centrality of the IPCC in climate change research and policy, it is not surprising that the IPCC framework is the most prevalent. However, IPCC defines the three key dimensions in very broad terms, leaving it up to individual researchers to operationalize them as they see fit. The profusion of approaches we found under the rubric of IPCC suggests that just because a researcher claims to use the IPCC framework does not mean they are doing same kind of research as others who also say they use that framework. Among the articles that actually defined them, the operationalizations of "exposure" and "sensitivity" were reasonably consistent, with exposure drawing on meteorological data and sensitivity capturing the degree to which climate phenomenon affect key biophysical processes (i.e. crop or pasture productivity).

The common claim of papers to assess a state of vulnerability was critically unpacked in terms of how they operationalized the frameworks to assess vulnerability across the various constructs. A key dimension of how researchers operationalize their vulnerability frameworks is how they deal with the unit of measure, and the degree to which they approach vulnerability and adaptive capacity as emergent properties of systems (outcomes) versus as dynamic social processes that occur through human agency. The analysis of vulnerability itself revealed that the majority of the papers followed the IPCC in using "a system" as the unit of reference, many drawing on direct quotes of IPCC AR3. However, two papers clearly indicate an orientation on actors and agency in their definitions of vulnerability, representing an important variation on the choice of how to conceptualize vulnerability.

> "Vulnerability generally refers to the propensity of some unit of exposure to experience harm. In practice, households are often a convenient unit of analysis for

> vulnerability assessments that aim to differentiate a population in terms of sensitivity to a particular stressor and capacities to effectively respond (Eakin and Luers 2006). At the household level, vulnerability is often evaluated by assessing exposure (the physical relation of the household to a stressor) and sensitivities to the losses experienced (e.g., what the impact means for the household's function and survival), as well as by the households' ability to cope and adapt, or its ''adaptive capacity,'' prior to and after experiencing loss" (Eakin et al. 2012).
>
> "Vulnerability is thus comprised of risks (or a chain of risky events) that people confront in pursuit of their livelihoods, the sensitivity of the livelihood to these risks, the risk response or the options that people have for managing these risks and finally the outcomes that describe the loss in well-being" (Notenbaert et al. 2013).

There was more variability in how researchers operationalized adaptive capacity (Table 1). Definitions range from direct quotes from the broad IPCC language to fairly specific descriptions of the constituent aspects of adaptive capacity. While most of the 12 definitions of adaptive capacity stay at the level of "systems", only Berkes and Ross (2013) specify that human agency is a component of adaptive capacity, though they immediately point out that it is not a well-understood phenomenon. However, by pointing toward individual's ability to change behaviour or circumstances, Marshall (2010) and Sietz et al. (2012) implicitly address the importance of agency. Tesso et al. (2012), emphasize that a system's capacity "is generated from the implementation of adaptation and interventions". While it is unspecified who is responsible for interventions, this strongly implies that adaptive capacity is primarily located in processes of planned change through policy and development initiatives.

Table 1: Definitions of adaptive capacity

Author	**Definition**
Antwi-Agyei et al	Adaptive capacity in the context of climate change has been defined by the IPCC (2007, p. 869) as ''the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.'' Adaptive capacity connotes some positive attributes of a system that enable it to reduce the adverse impacts (vulnerability) associated with climate change (Engle 2011).
Baca et al	In contrast, adaptive capacity is defined as a system's ability to adjust to climate change in order to reduce or mitigate possible damage [3]. Adaptive capacity is dynamic, and depends partly on the society productive base, such as: natural and artificial assets, social benefits and networks, human capital and institutions, governance, national income, health and technology [2], and how much capability a society has to adapt to the changes so as to maintain, minimize loss of, or maximize gain in welfare.
Berkes & Ross	Adaptive capacity is the capacity of actors in a system to influence resilience (Folke et al. 2010), and often works through social networks and learning communities (Goldstein 2012). We view adaptive capacity as a latent property, which can be activated when people exercise their agency. The processes by which this occurs have not been well explored.
CARE	The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.
Fussel & Klein	Adaptive capacity: The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.
Hahn et al	Adaptive capacity is the system's ability to withstand or recover from the exposure (Ebi et al., 2006).
Jamir et al	As per the IPCC's definition and framework, vulnerability is understood as a function of three components—exposure, sensitivity and adaptive capacity. Vulnerability is defined as ''the degree to which a system is susceptible to or unable to cope with, adverse effects of climate change, including climate variability and extremes'' (IPCC 2001).

Luers et al	We define adaptive capacity as the extent to which a system can modify its circumstances to move to a less vulnerable condition (Fig. 1c). We quantify adaptive capacity (A) as the difference in the vulnerability under existing conditions and under the less vulnerable condition to which the system could potentially shift: A = V (existing conditions) - V (modified conditions)
Marshall	It refers to the ability of individuals or communities to adapt to adversity and stressful life-events by 'reorganizing' through networks or institutions that learn, store knowledge and experience and are creative, flexible and novel in their approach to problem solving (Vayda and McCay, 1975; McCay, 1981; Sonn and Fisher, 1998).
Piya et al	Adaptive capacity is the ability of a system to adjust to climate change including climate variability and extremes, to moderate the potential damage from it, to take advantage of its opportunities, or to cope with its consequences. Selection of indicators for adaptive capacity is based on the DFID sustainable livelihoods framework, whereby adaptive capacity is taken to be a function of asset possession by the households (Jakobsen, 2011; Nelson, et al., 2010b).
Sietz et al	The adaptive capacity of smallholders (the term as used in this study encompasses the coping capacity) describes the ability to adjust to weather extremes, manage damages or explore alternative livelihood opportunities.
Tesso et al	According to Füssel and Klein, the risk-hazard framework (biophysical approach) corresponds most closely to sensitivity in the IPCC terminology while the adaptive capacity (broader social development) is largely consistent with the socio-economic approach [18]. In the framework, capacity is generated from the implementation of adaptation and mitigation interventions [18].

Looking across the definitions, other factors specified as constituents of adaptive capacity include ownership of (various) assets, social support networks, learning networks, access to technology, institutional flexibility, governance structures and practices, DFID's sustainable livelihood components, and health status. These concepts are themselves broad and variably operationalized. Concepts are made meaningful through the ways that they are operationalized and constituted through empirical data. Table 2 describes the operationalizations of adaptive capacity offered in articles that provided information sufficient to be able to link interpretable individual research methods to the concept 'adaptive capacity' and which have been assessed in our review as empirically valid (see transparency and validity assessment for more information). There are several items that appear on the table multiple times, such as livelihood diversification, education levels, irrigation, dependency ratio, farm size, etc., perhaps indicating some consensus on their importance. However, it is noteworthy that the same variable is often used to operationalize different concepts. For example, "Livestock" is variously treated as "Natural Capital" or "Financial Capital"; both "Credit" and "Membership in Community Organization" are treated as "Social Capital" and "Financial Capital", indicating less consensus on the links between empirical foundations and conceptual clarity than might be supposed in authors who draw on the livelihoods five capitals approach.

Table 2: Operationalizations of Adaptive Capacity

Subconstruct (level 1)	Subconstruct (level 2)	Indicators	Articles
Livelihood Assets	Social Capital	Community organization membership	Piya et al
		Access to credit	
	Physical Capital	Irrigation	Antwi-Agyei et al
		Communication devices	
		Type of house	Piya et al
		Communication devices	
		Distance to road	
		Irrigation	
	Natural Capital	Farm size	Antwi-Agyei et al
		Tenure system	
		% of productive land	Piya et al
		Livestock	
	Financial Capital	Credit	Antwi-Agyei et al
		Livestock	
		Remittances	
		Household income	Piya et al
		Livelihood diversification	
		Household savings	
		Livestock	
		Membership of community orgs	
	Human Capital	Education Level	Antwi-Agyei et al
		Health Status	
		Education	Piya et al
		Dependency	
		Trainings	
Socio-demographic profile; livelihood strategies; social network	Socio-demographic profile	Dependency ratio	Hahn et al
		Female headed households	
		Uneducated headed households	
		Households with orphans	
	Livelihood strategies	Households working elsewhere	Hahn et al
		Livelihood diversification	
		Agriculture dependent household	
	Social network	Receive/give ratio	Hahn et al
		Borrow/lend ratio	
		Independent of local government	
Direct Operationalizations		Number of cultivated production zones	Sietz et al
		Crop area	
		Livestock units	
		Potato productivity	
		Quinoa productivity	
		Education level of household head	

Local off-farm income and remittances

In addition to the IPCC vulnerability framework, the articles reviewed provided a fully developed description of the Vulnerability as Expected Poverty framework. The papers that constitute this framework emphasized how climate shocks contribute to impoverishment of households or communities. By emphasizing consumption level, food security or asset ownership as the indicators of vulnerability papers within the framework, VEP propose that projected poverty is the meaningful negative outcome related to climate vulnerability (Table 3). Subsequent operationalizations of "poverty" (Table 4) rely on household financial indicators as well access to production technologies. Transparency of the empirical foundations was a challenge in this group, however, primarily through the use of citations to specify details.

Table 3: Definitions of Vulnerability to Expected Poverty variants

Authors (*variant*)	**Definition**
Deressa et al *(Expected poverty)*	This method is based on estimating the probability that a given shock or set of shocks will move household consumption below a given minimum level (such as a consumption poverty line) or force the consumption level to stay below the minimum if it is already below this level (Chaudhuri et al. 2002).
Chhihn and Poch *(household vulnerability as expected poverty)*	Household vulnerability as expected poverty is defined as the probability that households will move into poverty given certain environmental shocks, current poverty status and household characteristics of respondents.
Échevin *(household vulnerability to poverty)*	We can define vulnerability to poverty as the probability of falling into poverty when one's consumption/income falls below a predefined poverty line.
Sarris and Karfakis *(rural household vulnerability)*	Thus a household is said to be vulnerable to the outcome of a risk event, if it does not have sufficient resources to adequately contend with the risk event. In other words, the extent to which a household is vulnerable to a risk event, namely the extent to which the household can become and/or remain poor or food deprived, depends on the size of the risk event and how effective the household is in managing the risk event. Considers vulnerability as the probability of consumption falling below a poverty threshold (Christiaensen and Subbarao 2004, Chaudhuri, et. al. 2002),
Calvo and Dercon *(vulnerability to poverty)*	In this article, we explore the notion of vulnerability to poverty, closely linked with the magnitude of the threat of poverty, measured ex-ante, before uncertainty has been resolved. [...] Remarking that we are interested in vulnerability to poverty will also be useful to pre-empt any confusion with vulnerability to downfalls in wellbeing. Our reference point is an absolute poverty norm (e.g. as in Chaudhuri 2003; Suryahadi and Sumarto 2003,or Christiaensen and Subbarao 2005), and not the initial individual position.

Table 4: Operationalizations of Poverty

	Indicators	Articles
Direct Operationalizations	Income and 4 different poverty lines	Deressa et al
	Annual per capita total expenditure	Sarris & Karfakis
	Annual per capita total income	
Cereal Production	Arable land owned	Mutsvangwa
	Crops grown and areas allocated to the crops	
	Yields obtained	
	Farming implements available	
	Availability of draft power	
	Livestock owned	
	Crop management practices	
Excluded		Calvo & Dercon: Not transparently operationalized
		Chhihn & Poch: Not transparently operationalized
		Capaldo et al: Not transparently operationalized
		Échevin: Not Valid/feasible
		Gunther & Harttgen: Not Valid/feasible

This section has presented the fully operationalized frameworks in terms of how they are conceptually constituted and how some of the key concepts are then operationalized through use of empirical data. Space precludes full elaboration of the uneven frameworks and all concepts, but that information, including options among fully transparent operationalizations of core constructs, can be found in the full Systematic Review Technical Report. However, many of the insufficiently operationalized frameworks appear to deal with overlapping concepts, particularly variants on "livelihoods", "household assets" and "poverty".

Finally, looking one step beyond the indicators used, Table 5 assesses the nature of actual data collected (as reported) to constitute these indicators. In particular, it explores the degree to which data presented are based upon objective measure (like precipitation data from a weather station) versus subjectively mediated data such as that reported by informants in interviews or in response to questionnaires. It is essential to note that "subjective" and "objective" should not be conflated with "qualitative" and "quantitative". There were a total of 53 constructs whose measurements were entirely taken by asking informants questions. Of these 53 constructs, 12 were subjective (e.g. informant's perception of risk) while the remaining 41 were objective (e.g. what is the actual climate variability). Some constructs appear in multiple categories because different articles approached them in a variety of ways. For example adaptive capacity was measured through a survey questionnaire, through combination of survey and meteorological/remote-sensing data and solely through meteorological/remote-sensing data.

Table 5: Nature of actual data collected

Subjective measures			
adaptive capacity	don't save crops	householder working far	no warning of disaster
ag. dependent households	don't save seeds	human capital	non-climatic stress
average precipitation	family with chronic illness	idiosyncratic shocks	non-labour prod. assets
borrow-lend ratio	farmer perceptions	impacts & resp. to disaster	% female-headed house.
cereal production	financial capital	inconsistent water supply	perception of adiha farmers
climate change	flood, drought, cyclone	independ. of government	physical capital
climate variability	food from family farm	injury or death fm. disaster	proximity to health facility
community	food security	inverse water stored	proximity to water source
community level	household characteristics	labour	receive-give ratio
covariate shocks	household consumption	livelihood diversification	social capital
crop diversity	household level	maximum temperature	struggle for food
dependency ratio	household level resilience	natural capital	uneducated head house
determinants of resilience	households with orphans	natural water source	water conflict
			week illness

Probable subjective measures	**Mixed subjective - objective measures**	**Objective measures**	**Not interpretable**
agricultural vulnerability	adaptation strategy	adaptive capacity	adaptive capacity
biophysical vulnerability	adaptive capacity	drought	community level
current exposure to risk	exposed & sensitive to cc	exposure	covariate shocks
current socio-econ. chars	financial capital	meteorological observation	entity
demographic vulnerability		resilient /vulnerable communities	exposure
financial capital		risk of climate change	household level
human capital		sensitivity	idiosyncratic shocks
natural capital		system state vs damage threshold	institutional environment
physical capital		threshold to damage	stimulus
sensitivity		wellbeing	structural poverty
social capital			
socio-econ. vulnerability			
vulnerability threshold			

Discussion

Heterogeneity in the field

The first lesson that emerges from the comparative analysis of research on local level vulnerability to climate change is that there is substantial heterogeneity in frameworks, concepts and operationalizations used in the research community. As climate vulnerability is a fairly new research field, this profusion of approaches represents a positive indication that researchers are creatively grappling with the challenge of how to make the concept meaningful and useful. However, this same diversity makes it very difficult to conduct synthetic analyses across studies or at least to draw robust realist conclusions about patterns of climate vulnerability in smallholder systems. Because so many studies use different frameworks, different suites of concepts and/or different operationalizations of the same concept, it is difficult to avoid the conclusion that even though researchers are talking about the same topic, empirically they are not really talking about the same thing. In other words, at the current time it is difficult if not impossible to identify empirically supported patterns of climate vulnerability determinants through a review of the literature. Even where studies appeared to have strong internal and external validity, the uniqueness of each study means that it is not possible to draw strong conclusions about causal pathways based on synthetic analysis of evidence.

For example, the IPCC vulnerability framework is clearly, and unsurprisingly, the touchstone approach in the field. However, among the 12 different high quality studies reviewed that use the IPCC framework, there is high degree of variability in what those studies actually examined empirically. The name "IPCC framework" and its three component concepts (Sensitivity, Exposure and Adaptive Capacity) might be the only things that are actually common among these studies. It is noteworthy that the variability within the IPCC-based studies was not evenly distributed, with relatively greater agreement found in exposure and sensitivity and greater divergence found in adaptive capacity. We believe that as exposure consists of more clearly observable biophysical phenomenon there is greater agreement, or at least less apparent disagreement, on how to approach its characterization. While sensitivity has a stronger social dimension, its measure is still largely informed by the ways that the biophysical phenomenon (characterized in exposure) affect key economic or livelihood outcomes, such as crop productivity.

Adaptive capacity, however, appears to be more challenging. The variability in the operationalization of adaptive capacity reflects how researchers struggle to characterize the extraordinary complexity of social systems and social practices, especially in how they are able to simultaneously respond to both biophysical and social signals. As such, much of the remaining discussion focuses on research challenges that our study identified in deciding what constitutes, or should constitute, core common aspects in the operationalization of adaptive capacity for research and evaluation within the CCAFS network.

If we accept that frameworks and concepts are ultimately substantiated through the modes of operationalization and methodologies of measure, the diversity of indicators used suggests that each IPCC-based study effectively proposes or hypothesizes its own framework and constituent concepts. In effect, the "IPCC vulnerability framework" seems essentially to be a placeholder that helps legitimize and politically situate research, but is not meaningful in terms of predicting empirical comparability upon studies claim to fall under that rubric. Assuming comparability within studies that claim to use the IPCC framework may lead to confusion in the field. However, one implication of the range of diversity (or lack of coherence) within the IPCC-based work is that despite its apparent predominance, we cannot

assume that approaches outside of the IPCC framework do not have substantial contributions to make to analysing climate vulnerability.

Vulnerability and scale of analysis

Although this entire study was explicitly focused on local level climate vulnerability research, we still found variability in the units of research. Following IPCC framing, the prevailing language around vulnerability, as well as adaptive capacity, centres on "a system". However, the publications included in our review ranged from focusing on "households" to larger aggregations such as "communities" (both of which are themselves slippery concepts, (see Beaman and Dillon, 2012)). This represents an important methodological choice in how to approach the study of vulnerability.

On one hand, many decisions and qualities regarding adaptive capacity (and thus vulnerability) can be said to occur at the household level, such as asset ownership, labour or mobility management, technological investment etc. Using atomized households as a unit of analysis, livelihood-based approaches have some potential for identifying socio-technical factors associated with vulnerability. However, this approach, like other indexbased approaches that look at vulnerability as a state of being to be made visible through the compilation of static indicators, misses the analysis of people's actual creative agency in dealing with climate stresses. This is significant because it sets up rural society as an analytical object that awaits external intervention, whether by policy or technology transfer, rather than viewing actors in rural society as dynamic partners with whom to engage. Furthermore, using such static household level analyses as a foundation for interventions risks directing attention toward addressing symptoms (indicators) of vulnerability rather than addressing root causes (drivers).

While they can make a legitimate analytical focal point unto themselves, household decisions and qualities can also be seen as occurring in complex social, economic, political and ecological networks. In effect, choosing to study a "community", whether as an economic system, an ecological system, an agricultural system, a social system or otherwise, implies it is more than just the sum of its parts (households). These contexts affect not only how vulnerability is distributed within a social system, but also how people respond, both as networked individuals and as collectivities (see Crane et al., 2011; Siregar and Crane, 2011). Even changes in household level practices can change higher-level systems in unpredictable and emergent ways that will not be visible through household level analysis. Furthermore, "upstream" activities, such as shifts in national policy environments aimed at reducing vulnerability (or otherwise) can only be understood as meaningful through cross-scale and networked analysis. Taking a community oriented approach enables local social structures to come into focus as potential mediators (positive or negative) of vulnerability. Even broader, cross-scale analysis (Eakin et al., 2009) enables the possibility of identifying larger scale and complex drivers of vulnerability.

Vulnerability to, or within, climate change?

Unlike the IPCC vulnerability framework, the Vulnerability as Expected Poverty framework is not inherently centred around climate shocks as the key shock to which people are vulnerable. Instead, VEP is based upon dynamics that create and perpetuate poverty. The papers analysed in our study simply represent a sample of VEP work that includes climate as an aspect of poverty and food security outcomes. The origin of the VEP approach from outside of climate vulnerability studies is a part of what makes its contributions particularly interesting.

Concepts found in this set of papers provide approaches that allow climate vulnerability to be understood in the context of non-climatic drivers and broader contextual factors that produce

the social circumstances of vulnerability and poverty more generally. It is argued in many corners that bracketing climate vulnerability and adaptation away from other dynamics of social and environmental change will lead to a poor understanding of how to engage. Where the IPCC framework would ask how climate shocks drive people to poverty, VEP would ask how the already complex socio-environmental dynamics of poverty creation are affected by climate shocks as an additional stressor. By implicitly asserting that vulnerability, in general, emerges through complex and multi-faceted social processes, VEP opens doors for questions that do not assume the primacy of climate as a driver of vulnerability. While this is not always explicit in the VEP publications, the implication is that secondary social mechanisms that contribute to, intersect with or compound climate vulnerability are relevant to include.

That being said, the tendency within VEP to equate vulnerability to a poverty outcome appears narrow when examined from the perspective of other frameworks. While poverty and food insecurity are certainly keys indicators of vulnerability, making them the only indicators elides a much broader spectrum of complex outcomes that deserve a place in climate vulnerability discussions, including but not limited to ecological degradation, migration (Meze-Hausken, 2000), and undesired cultural transformations (Crane, 2010). Furthermore, like with other index-based approaches, econometrics risks glossing over people's agency in adapting to climate change.

Contributions and constraints of systematic review

Systematic review is known to be a resource-intensive form of research and underestimation of workload involved is common (Wallace et al., 2004). Despite this, we believe our systematic review has produced findings that validate this extra effort. This is illustrated when it comes to interrogating the terminology used by authors. For instance, to code the studies' theoretical approaches, a coding structure was used that grouped authors' declared approaches into four categories (IPCC; VEP; Livelihood Approach; Food Security). These categories were later examined according to the presence of constructs, with the result that only two (IPCC & VEP) of these approaches were found to be empirically defensible as classifiers. Studies that were initially coded as either of the other two frameworks were either subsumed as variations of one of the two dominant approaches, or were found to only be present in one article.

Similarly at the level of constructs, inductive coding based on authors' reporting of constructs identified 114 constructs of which roughly 100 appeared in only one article each. During scrutiny of constructs, five frequently occurring constructs were split into nine after definitions were examined; 26 constructs with different names were subsequently merged into seven; and 37 article-specific constructs could not be compared because definitions were not provided. This shows the value of a systematic approach in that it offers not only authority through rigour, but also can produce certain findings that would be missed in a review that did not look beyond authors' terminology.

As such, the data generated in this review will allow a more informed decision to be made when selecting methods and indicators to study vulnerability, as well as making explicit the extent to which results can be compared between studies. Not only will this benefit CCAFS in designing their own study, but we believe it can also contribute to the development and refinement of the domain of vulnerability as a field of study. This study has shown that there are many existing approaches to studying vulnerability. Efforts to consolidate these approaches appear chiefly to take the form of a re-iteration of the definitions in the IPCC framework, though operationalizations still vary widely.

The systematic method we have adopted is an attempt to move toward consolidation of research approaches through *empirical description* (i.e. 'this is what people say they are actually doing and only some of it seems to make sense') rather than *normative argument* (i.e.

'I'm and expert and I think we should do as follows."). Further, explicitly using a transparency assessment in reading reports of research encourages authors to report their research to a standard that will be recognized as transparent. The studies in the review came from a range of disciplines and ranged from theses to conference papers to peer-reviewed articles. From this variety of reporting formats, our transparency instrument was designed to retain only those operationalizations which reported information sufficient to support an assessment of validity. The fact that more studies were not found to have sufficiently transparent reporting should not be confused with low quality research. We suspect that this is at least partly a function of contemporary culture and practice of academic publishing. In some disciplines research methods are so standardized that it is no longer necessary to describe methods in detail and the standard format of peer-reviewed publications typically limits the length of articles to 6000-8000 words, with incentives to highlight empirical findings and novelty over richly developed conceptual and methodological precision. We would expect systematic studies, such as this one, will improve reporting practices in the field which will support empirically grounded standardization of research methods that consequently improves the quality of research.

The methods used for this review were designed especially for this project. It builds on a number of existing reviews which use systematic review methods to study elements of the research process – namely identifying frameworks (Carroll et al., 2013), building frameworks (Carroll et al., 2013; Dubois et al., 2013); identifying concepts (van der Lee et al. 2007; Le Reste et al. 2013; Carroll et al. 2013), synthesizing concepts (Le Reste et al. 2013), and identifying research methods or operationalizations (Bing-Jonsson et al., 2013; van der Lee et al., 2007). However, it appears that the present review is unique in covering all of these elements in a single study. Another methodological novelty of our study is the dialogue between empiricism and expertise in the review process, in that assessments made by either systematic scrutiny or expert judgement were cross-checked by one another. Both the combination of existing methods and the dialogue between empirical description and expert judgement appear to have been successful.

There were a number of things that could not be addressed in this study. First, important data were 'lost through citation.' Where authors did not fully report their research or theoretical frameworks in the report, but cited works where such details can be found, we did not chase these sources. This is not a failure of design but, simply, an argument for allowing more resources for the systematic review research process.

Secondly, although a goal of the initial review effort was to identify causes and drivers of vulnerability, it was not feasible withing the scope of this study. Within the literature, we found that was impossible to systematically distinguish between concepts that deal with vulnerability as a *state of being* (indicators), as opposed to *drivers* (determinants) of vulnerability. There were two reasons for this. First, there was neither consistency across articles in terms of vulnerability outcomes (e.g. the potential problems that one faces when vulnerable, as opposed to vulnerability as the probability to face potential problems). Furthermore, there was no consistency in terms of drivers and underlying notions of causality (e.g. causal relations; determining factors contributing to particular outcomes; or composite factors influencing a state which itself is defined by an index of such factors). As such, a justifiable structure could not be produced within which to categorise these constructs. This represents an important finding for the field of vulnerability research. Although they are often difficult to distinguish in the literature, measuring vulnerability as a state of being or outcome (how do we know vulnerability exists?) is linked to but a very different research objective than analysing the causes and drivers that produce vulnerability (given some notion and measurement of vulnerability, why does it exist)?

Thirdly, the results of this study could be strengthened with a more developed quality appraisal. Quality was ensured mostly through a validity assessment that used expert review

to exclude research instruments from the review. However, an improved review should use empirical as well as more involved expert methods to appraise quality. For instance, the ultimate interest in assessments of vulnerability tends to be objective conditions such as rainfall, crop yields, household assets and alternative livelihood strategies.

When we were assessing the validity of the operationalizations of constructs we identified 79 constructs for which we could determine both how data was gathered and about what the author was drawing conclusions. Of those 79 instances, 62 constructs referenced objective conditions like assets or yield. For those 62 constructs that referenced objective conditions we found in 48 instances that researchers relied on subjective data such as that produced by surveys or interviews. While we were pleased to note that these authors reported with sufficient transparency to link individual data collection methods to constructs, we found no discussion of whether authors were justified in relying on subjectively mediated data in drawing objective conclusions. Our intent here is not to suggest that objective measures are either more valid or preferable. Rather, what we were looking for and did not find was any discussion of measurement error that recognized the methodological challenges that come with securing valid data from human informants. What we are interested in here is unremarked use of subjectively mediated measures in quantitative studies.

While this can be analytically and programmatically convenient, it risks giving an inflated confidence in the substance and precision of findings. If subjective measures are so well established that it is no longer necessary to document their validity, then there is no cause for concern. If, however, this is not the case, then there is reason to empirically test whether data arising from subjective measures are adequate for the purposes for which they are used. Any readers interested in a follow-up study to this review are directed especially to these three issues: citation, causes vs. drivers and assessing quality of operationalizations. We also recommend they be addressed through combination of empirical study and expert review.

Conclusions and Recommendations

Through analysis of the existing literature, this systematic review has outlined a range of possible ways to study climate vulnerability, summarising a range of options from which to construct a programmatic approach. However, that being said, our research has also created a range of options which are not concrete with unknown provenance and unproven quality. Consequently, rather than recommending a wholesale adoption of a particular framework, approach, or methodological system, we instead look to recommend a variety of aspects represented in the reviewed work with an eye toward testing various approaches to the study of local-level vulnerability to climate change.

As outlined above, a key question is whether the objective is to describe vulnerability as an outcome/state of being through a set of indicators, or to analyse the production of vulnerability as a process through which numerous determinants and drivers interact to cause specified outcomes. While our systematic review has found a diversity of approaches to studying vulnerability, we have relatedly found a lack of clear scientific validation of those approaches at the conceptual and operational levels, including clarity on whether the question is to identify indicators or drivers of vulnerability. Consequently, we recommend that further research in the field of vulnerability studies should be explicit about which of these objectives is being pursued, both in terms of research design as well as language used to describe it. For example, research questions and operationalizations should clearly indicate which of the following questions they are attempting to answer:

1) Is this system vulnerable?
2) How vulnerable is this system?
3) To what is this system vulnerable?

4) How is vulnerability distributed within the system?
5) What is causing this system to be vulnerable?

Both vulnerability as outcome and vulnerability as process can theoretically be studied through linking across scales, ranging from households, to communities, to regional and national governments. However, they imply very different research questions and data sets. The report we analysed exhibited great diversity, implicit and explicit non-agreement, and objective conclusions being reached through subjective data and/or poorly validated research instruments. We propose that vulnerability indicators should ideally be closely tested, scrutinized and validated before institutionalizing them under the assumption that they provide an accurate understanding of the phenomena they aspire to describe. As such, we recommend empirical testing of both vulnerability models and measures. This testing should apply to vulnerability indicators and vulnerability drivers, the two being significantly intertwined. This task has been begun in this review through the identification of indicators used to transparently operationalize core constructs (for these readers are directed towards the full Technical Report, especially Appendix O and P). This now needs to be taken further.

If CCAFS wants valid and comparable measures of vulnerability and adaptive capacity that support aggregation, but do not lose household level resolution necessary to support programming, CCAFS should experimentally develop an approach that tracks vulnerability (and thus adaptive capacity) through a set of indicators that mix some form of (objective) asset/poverty measures at the household level with (subjective) governance and policy factors at the community and national levels. While agricultural technologies (household level assets) are one aspect of adaptive capacity, evidence suggests that networked and cross-scalar dimensions (such as the ability to actively engage in policy processes that create enabling environments) capture changes in social dimensions that household level analysis will not capture.

Recognizing that the causes of climate vulnerability are not just driven by exposure and biophysical sensitivity to climate events, but the social dimensions of adaptive capacity, the networked and cross-scalar approaches are important for understanding the drivers of climate vulnerability. Institutional interventions, well beyond farm or even community boundaries, can effectively improve smallholders' livelihoods, even facilitating the adoption of on-farm technologies (Röling et al., 2012; Röling et al., 2014). Following on this, analysis of the contextual drivers of vulnerability – including, for example, policy environments, governance structures and practices, the organisation of value chains, customary gender and tenure institutions, etc. – will be important for recognizing off-farm, non-local sorts of interventions that can contribute to reducing smallholder vulnerability to climate change.

Eakin et al's (2009) "nested vulnerability" framework and related concepts are relevant because they recognize that local level vulnerability is substantially shaped by extra-local social phenomenon. For example, new climate information services, development of national policies and shifts in international development agendas work across multiple impact pathways and Flagship programs that address climate vulnerability. Applying the concept of "teleconnections" to the social dimensions of vulnerability permits analysis across diverse social locations, complex mechanisms of vulnerability creation that combine both climatic and non-climatic events as well as second-order effects of climate.

From the point of view of scientific innovation, the profusion of a diverse array of approaches to researching climate vulnerability is positive development. However, from an institutional or programmatic point of view, such as that of CCAFS, an array of choices does not necessarily provide clear guidance for which approach is most appropriate, effective or useful. The problem of incomparability of vulnerability studies has been observed in programmatic contexts elsewhere, such as the Indian State Action Plan on Climate Change, which (Dhanapal and Panda, 2014). As with a monitoring and evaluation system for tracking

vulnerability indicators, the frameworks and methods for the analysis of complex interactions of vulnerability drivers deserves systematic and rigorous experimentation in order to develop tools that can be confidently applied at the programmatic level.

Annexes

Annex 1: Databases used in literature search

- AJOL
- AGRICOLA
- AGRIS
- Ingenta Connect
- JSTOR
- Mendeley
- Google Scholar
- Science Direct
- Scopus
- SSRN (Social Science Research Network)
- Springer Link
- Web of Knowledge
- Web of science
- Scirus
- Ebscohost

Annex 2: Search terms used in screening stage

- Poverty and vulnerability to climate risk
- Rural livelihoods and vulnerability
- Food insecurity and climate risk
- Climate variability and household vulnerability [and community]
- Causes of vulnerability
- Agriculture and climate change and vulnerability outcome
- Agriculture and food security and climate change
- Vulnerability and household agriculture
- Food insecurity and household poverty
- Climate hazards and vulnerability
- Searched using vulnerability and secondly with assessment:
- Climate risk and vulnerability [assessment]
- Climate change and vulnerability [assessment]
- Food insecurity and vulnerability [assessment]
- Poverty and vulnerability [assessment]
- Climate and floods and vulnerability assessment]
- Households and vulnerability [assessment]
- Climate and drought and vulnerability [assessment]
- Vulnerability status and climate impact
- Gender and climate change and vulnerability
- Household level vulnerability to climate change
- Poverty and vulnerability
- Climate risk assessments [and households / communities]
- Climate change vulnerability and hazard exposure
- Climate change risks and household characteristics
- Sensitivity and climate change risk and vulnerability status
- Droughts and household food security and vulnerability
- Floods and household food security and vulnerability
- Climate risk [and hazard] and food security
- Vulnerability determinants and climate change
- Institutions and vulnerability outcomes
- Determinants of [household] vulnerability
- Local level vulnerability assessment climate change
- Household vulnerability and climate change case studies

Annex 3: Summary of data extraction process

Paper #	Title	Lead Author	Publication Date	Pass review	Comments
Paper 1	Characterizing the nature of household vulnerability to climate variability: empirical evidence from two regions of Ghana	Antwi-Agyei	2012	Yes	Application of the sustainable livelihoods framework to direct the approach. Excellent mix of methodologies and analysis to derive final causation and determinants.
Paper 2	Assessment of climate change vulnerabilities in Kangpara Gewog, Trashigang	UNDP	2012	No	Descriptive methodology on a single project. No analytical methods to determine factors contributing toward vulnerability in the site.
Paper 3	Climate change vulnerability assessments in Miombo Woodlands. WWF.	Shumba	2012	No	Descriptive methodology, no determinants or causation laid out.
Paper 4	Assessing vulnerability of selected farming communities in the Philippines based on a behavioral model to agent's adaptation to global environmental change.	Acosta-Michlik	2008	Yes	Cited accompanying paper to justify some of the methodological approaches.
Paper 5	Assessing household vulnerability to climate change. The case of farmers in the Nile Basin of Ethiopia	Deressa	2009	Yes	Statistical analysis of agro-ecological zones and income levels as key factors determining vulnerability.
Paper 6	A Cross-Sectional, Randomized Cluster Sample Survey of Household Vulnerability to Extreme Heat among Slum Dwellers in Ahmedabad, India	Tran	2013	No	Good use of statistical regression and correlation, but outcomes were focused on heat related morbidity and effect of heat, rather than heat as one contributor to household vulnerability.
Paper 7	A method for quantifying vulnerability, applied to the agricultural system of the Yaqui Valley, Mexico	Luers	2003	Yes	Range of methods including statistical regression and spatial analysis. The paper provided a framework for assessing the relative importance of market fluctuations compared to temperature changes in determining vulnerability. Wheat

					yield was the outcome variable of concern in delineating vulnerability.
Paper 8	A Simple Human Vulnerability Index to Climate Change Hazards for Pakistan	Khan	2012	Yes	Range of methods and statistical approaches utilized. Outcomes showed significant factors at district level vulnerability. Robust regression to test the causation elements the authors identified.
Paper 9	Derivation of a household-level vulnerability index for empirically testing measures of adaptive capacity and vulnerability	Notenbaert	2013	Yes	Regression and correlation analysis of determinants that were used in the household vulnerability index. Good use of literature to explain the causal relationships illustrated by the statistically significant variables.
Paper 10	Who is susceptible and why? An agent-based approach to assessing vulnerability to drought	Kromker	2008	No	Range of modeling and index development, but approach was focused on susceptibility to drought and psychological response. Outcomes for India case study (fits criteria of geographic scope of systematic review) are descriptive rather than outlining key causes of vulnerability.
Paper 11	Climate vulnerability index - measure of climate change vulnerability to communities: a case of rural Lower Himalaya, India	Pandey	2012	No	Description of Composite Vulnerability Index and components between households near to the administrative headquarters and those far. Statistics carried out, but description of significant correlates and invalidated assumptions.

Paper 12	Climate variability and farmer's vulnerability in a flood-prone district of Assam	Chaliha	2011	No	Composite Vulnerability Index was derived and taken to be representative of the agricultural vulnerability of the farmers of the district with respect to floods. Indices calculated were apportioned weights according to the ranks assigned to the sources of vulnerability. This was done by the farmers based on their perceptions during the Participatory Rural Appraisal. Outcome was a weighted biophysical, agricultural, socio-economic vulnerability indices of study villages. No correlation of causation of specific indicators.
Paper 13	Climate variability and change or multiple stressors? Farmer perceptions regarding threats to livelihoods in Zimbabwe and Zambia	Mubaya	2012	Yes	Descriptive statistics and participant ranking of stressors linked to climate variability. Points allocated by participants to each stressor under a specific criterion.
Paper 14	Climate Change Impacts on Agriculture and Vulnerability as Expected Poverty of Kampong Speu Province, Cambodia	Chhinh	2012	Yes	The study aimed to identify the impact of environmental shocks (flash floods, windstorms and drought) and household characteristics on per capital income. Vulnerability indexes to predict future poverty incidence in the communities were produced.
Paper 15	Vulnerability to Weather Disasters: the Choice of Coping Strategies in Rural Uganda	Helgeson	2013	No	Focus was on analysis of coping strategies rather than vulnerability determinants.
Paper 16	Multi-Agent Modelling of Climate Outlooks and Food Security on a Community Garden Scheme in Limpopo, South Africa	Bharwani	2005	No	Investigated the effect of a climate scenario and resulting market effects, did not illustrate additional vulnerability factors
Paper 17	Adaptation to climate change and variability: farmer responses to intra-seasonal precipitation trends in South	Thomas	2007	No	The study analyzed and coded qualitative data for risk factors but focus was made on adaptation and coping rather than vulnerability.

	Africa				
Paper 18	Adapting agriculture to climate change in Kenya: Household strategies and determinants	Bryan	2013	No	Assessed determinants of adaptation versus vulnerability.
Paper 19	Analysis of vulnerability and resilience to climate change induced shocks in North Shewa, Ethiopia	Tesso	2012	Yes	Principal component analysis used to outline vulnerability factors, with relation to agro-ecological zones.
Paper 20	Application of Fuzzy Cognitive Mapping in Livelihood Vulnerability Analysis	Murungweni	2011	No	Used three scenarios to construct fuzzy cognitive maps for livelihood analysis. Results show qualitative patterns where different vulnerability factors emerge.
Paper 21	Can farmers' adaptation to climate change be explained by socio-economic household-level variables?	Below	2012	No	Multi-linear regression model to look at factors. Focused was placed adaptation interventions
Paper 22	Community Vulnerability to Floods and Landslides in Nepal	Samir	2013	No	Assessed the relative importance of socioeconomic factors associated with differential community vulnerability to floods and landslides in Nepal. Results from regression were used by authors to describe patterns and assumptions of vulnerability
Paper 23	Effects of Landscape Segregation on Livelihood Vulnerability: Moving From Extensive Shifting Cultivation to Rotational Agriculture and Natural Forests in Northern Laos	Castella	2013	No	Developed an analytical framework for assessing the Impact of Landscape Segregation on Ecosystem Service Provision and Livelihood Vulnerability. No vulnerability determinants identified and descriptions used.
Paper 24	Food insecurity and vulnerability in Nepal: profiles of seven vulnerable groups.	Lovendal	2004	No	Workshops at national and sub-national level and focus group discussions at community scale. Descriptions of vulnerability made largely from summaries of national workshops.

Paper 25	Farmers' perception and knowledge of climate change and their coping strategies to the related hazards: Case study from Adiha, central Tigray, Ethiopia	Mengistu	2011	Yes	Hazard identification and characterization from the results of focus group discussions. Hazards were ranked by gender.
Paper 26	Farmers' perceptions of adaptation to climatechange and water stress in a South African rural community	Gandure	2013	Yes	Focus group discussions with farmers ranking factors causing changes to their livelihood including climate variability and change. Findings show age disaggregation important in ranking of hazard (e.g. unemployment vs. climate change for youth).
Paper 27	Farmers' vulnerability to climate variability in Dimapur district of Nagaland, India	Jamir	2013	Yes	Weights were assigned to the different indicators for obtaining the composite vulnerability index. Normalization of the values for each of the indicators was carried out. IPPC framework used to group indicators under the heads: demographic, biophysical, agricultural and socio-economic sources of vulnerability
Paper 28	Household vulnerability to climate change: Examining perceptions of households of flood risks in Georgetown and Paramaribo	Linnekamp	2011	No	Assessed direct impact of floods on households and where households took preventative action.
Paper 29	Insights into the composition of household vulnerability from multicriteria decision analysis	Eakin	2008	Yes	Development of indices based on survey data structured on livelihood capitals framework. Analytical hierarchy process applied for determining criteria weights. This was followed by compromise programming to rank households in terms of sensitivity and adaptive capacity. Fuzzy classification of households into vulnerability categories.
Paper 30	Institutional Change, Climate Risk, and Rural Vulnerability: Cases from	Eakin	2005	No	Livelihoods approach to explore vulnerability across three communities. Focus was on

	Central Mexico				household risk management strategies.
Paper 31	Land ownership and conflicts over the use of resources: Implication for household vulnerability in eastern Ethiopia	Bogale	2006	No	Study attempts to investigate factors associated with the choice of various property right institutional arrangements for sustainable use of the land resource. Regression analysis focused on land right and property regimes.
Paper 32	Livelihood Security, Vulnerability and Resilience: A Historical Analysis of Chibuene, Southern Mozambique	Ekblom	2012	No	Historical account and more focus on ways to reduce vulnerability
Paper 33	What drives food insecurity in southern Africa? A meta-analysis of household economy studies	Misselhorn	2005	Yes	Meta-analysis of local level Household Economy Approach (HEA), citation counts of direct and indirect drivers of food insecurity as component focus of vulnerability
Paper 34	Vulnerability to individual and aggregate poverty	Calvo	2012	Yes	Axiomatic approach to the measurement of both individual and aggregate vulnerability. Constructed a vulnerability profile, based on (multivariate) correlations of household vulnerability with a set of basic characteristics, such as demographics, assets, and other general household- and village-level characteristics
Paper 35	Vulnerability to climate change in rural Ghana: mainstreaming climate change in poverty-reduction strategies	Dasgupta	2010	Yes	Constructed an index of vulnerability to climate change, at the household level. The regional risk of drought using average annual rainfall data
Paper 36	Vulnerability of smallholder rural households to food insecurity in Eastern Ethiopia	Bogale	2012	Yes	Study adapted the Vulnerability as Expected Poverty (VEP) approach to food insecurity. The study scrutinizes factors that are associated with household level vulnerability to food insecurity by adapting VEP approach.

Paper 37	A model of vulnerability to food insecurity	Capaldo	2003	Yes	Developed a forward-looking model, which identifies the risks that households are exposed to while also estimating the magnitude of the impact of these risks on household food security. The model allows the relative vulnerability to food security given each typology of households to be estimated. Vulnerability factors and correlation were identified.
Paper 38	Estimating Households Vulnerability to Idiosyncratic and Covariate Shocks: A Novel Method Applied in Madagascar	Gunther	2009	Yes	The study analyses whether vulnerability is mainly driven by permanent low consumption prospects i.e. structural or poverty-induced vulnerability or by high consumption volatility i.e. transitory or risk-induced vulnerability. The study shows covariate shocks have higher impacts on rural households.
Paper 39	Dynamics of Chronic Poverty: Variations in Factors Influencing Entry and Exit of Chronic Poor	Dhamija	2008	Yes	Used panel data from three-year blocks to assess the emergence of poverty. A regression analysis showed household size and composition, and caste to be significant in affecting poverty
Paper 40	Characterizing poverty and vulnerability in rural Haiti: a multilevel decomposition approach	Echevin	2011	Yes	Two level modeling and regression analysis of the impact of both observable and unobservable idiosyncratic and covariate shocks on household economic well being. Findings related to climate shocks and interaction with income.
Paper 41	Growth and shocks: evidence from rural Ethiopia	Dercon	2004	No	Econometric approach to test for the impact of uninsured risk. Study measured recent and past shocks which were directly introduced in regressions, and their cumulative impact quantified. (In some regressions shocks had no explicit role to play in the formulation).

Paper 42	Measuring vulnerability to poverty	Kamanou	2002	No	Capture the idea of vulnerability by starting with micro-economic theory of risk & uncertainty. The study took the changes in per capita income and consumption to signal 'shocks' like price changes or low rainfall. The idea was to generate a distribution of possible future outcomes for households based on observed characteristics. Focus was on framework development and methodology, no determinants clearly outlined.
Paper 43	Modelling the economic vulnerability of households in the Phang-Nga Province (Thailand) to natural disasters	Willroth	2011	No	Aimed to assess economic vulnerability of households using a questionnaire based survey and remote sensing. This was integrated into a structural equation model (SEM). Focus of analysis was vulnerability to the Tsunami and not at additional determinants of vulnerability.
Paper 44	The impact of conflict on household vulnerability to climate stress: evidence from Turkana and Kitui Districts in Kenya	Eriksen	2005	No	Investigated the impact of conflict and violence on household vulnerability to climate stress. Descriptive analysis of interview outcomes and focus was on adaptation needs.
Paper 45	The rains are disappointing us: dynamic vulnerability and adaptation to multiple sytressors in the Afram Plains, Ghana	Westerhoff	2009	Yes	Application of a generic vulnerability framework to understand community relevant exposure sensitivities. Explored four key vulnerability determinants as outcome of exposure-sensitivity analysis.
Paper 46	Typical patterns of smallholder vulnerability to weather extremes with regard to food security in the Peruvian Altiplano	Sietz	2012	Yes	Pattern analysis where vulnerability-creating mechanisms based on similarities at household level were compared. The cluster analysis examined vulnerability profiles when exposed to weather extremes, with a focus on the food security aspects of vulnerability. The cluster analysis revealed four vulnerability patterns that depict typical combinations of household

					attributes, including their harvest failure risk, agricultural resources, education level and non-agricultural income.
Paper 47	Factors Affecting Households Vulnerability to Climate Change in Swaziland: A Case of Mpolonjeni Area Development Programme(ADP)	Nkondze	2013	Yes	Developed a household vulnerability index based on survey results
Paper 48	Resilient or Vulnerable Livelihoods? Assessing Livelihood Dynamics and Trajectories in Rural Botswana	Sallu	2010	Yes	Quantified the impact of different livelihood trajectories. The focus was more on resilience factors, however cluster analysis split the households into varying vulnerability levels.
Paper 49	Vulnerability and poverty in Bangladesh	Azam	2009	No	The study estimates the ex ante welfare of households. Estimates were made of both the expected mean and as well as variability of consumption, with the later being determined by idiosyncratic and covariate shocks. Focus places on idiosyncratic shocks and regression didn't pinpoint specific determinants.
Paper 50	Vulnerability to Covariate and Idiosyncratic Shocks and Safety Net Targeting of Rural Households with an Application to Rural Tanzania	Sarris	2010	Yes	Household surveys, secondary data and the estimation of crop income variability were collected. In addition time series data on market prices as well as a time series on regional production and rainfall. Quantitative analysis and regressions outlined key vulnerability factors of households in both surveyed districts.
Paper 51	Vulnerability of rural households to climate change and extremes: Analysis of Chepang households in the Mid-Hills of Nepal	Piya	2012	Yes	Household survey and subsequent Principal Component Analysis for IPCC vulnerability framework. The coefficient of the trends of climate variables (rainfall and temperature) was calculated using ArcGIS and calculated separately for each household. The PCA

					identified vulnerability determinants under sensitivity, exposure and adaptive capacity categories.
Paper 52	Current vulnerability in the Tri-National de la Sangha landscape, Cameroon	Devisscher	2013	No	Multiple data collection methods applied to understand vulnerability under a dynamic vulnerability framework, but analysis was qualitative descriptions of the survey and community results.
Paper 53	Rural Households: Socio-Economic Characteristics, Community Organizing and Adaptation Abilities	Bruun	2013	No	Used an existing socio-economic survey to identify livelihood changes and impact of climate. Some group of vulnerability was made with specific combinations of vulnerability factors. However the method was a qualitative descriptive review based on expert opinion of the author and local knowledge.
Paper 54	Livelihood Strategies Under the Constraints of Climate Change Vulnerability in Quang Nam	Casse	2013	No	Looked at vulnerability after a disaster (typhoon) and investigated the standard deviation of income levels to determine vulnerability factors and where significant interactions may have occurred. Key factors outlined were poverty, inequality and institutional adaptation. Analysis focused on the impact of the typhoon versus general vulnerability factors
Paper 55	Perceptions of climate change, multiple stressors and livelihoods on marginal African coasts	Bunce	2010	No	Carried out rapid rural appraisals and participatory field work in Tanzania and Mozambique with a small sample to understand stressors to livelihoods. Outlined climate change as a major factor but analysis was descriptive and based on small sample and not focused on additional vulnerability determinants.

Paper 56	Natural Resource Management Impact on Vulnerability in Relation to Climate Change: A Case in a Micro-Scale Vietnamese Context	Platten-Hallermund	2013	No	Small household survey and interview to find out changes. Descriptive analysis of results, methodology for analysis was not clearly laid out.
Paper 57	Poverty, vulnerability and the impact of flooding in the Limpopo Province, South Africa	Khandlhela	2006	No	Multi-dimensional approach to the analysis of vulnerability in the face of floods. Descriptive analysis of impact a specific flood had on communities and most affected assets and factors.
Paper 58	The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique	Hahn	2009	Yes	Developed an LVI for two communities in Mozambique to quantify the strength of current indicators in response to current exposure to climate extremes. Determined factors that contributed to increased vulnerability.
Paper 59	Exploring vulnerability and adaptation to climate change of communities in the forest zone of Cameroon	Bele	2013	No	Assess local people's vulnerability to climate change in the humid forest zone of Cameroon in order to understand how they are affected and respond and to identify their specific needs for adaptation. Analysis was through descriptions and focus was on climate factors and impact on livelihoods.
Paper 60	Vulnerability Assessment of Weather Disasters in Syangja District, Nepal: A Case Study in Putalibazaar Municipality	Shrestha	2005	No	This assessment includes analysis of current vulnerability as the quantitative integration of physical and socio-economical vulnerability, analysis of existing qualitative adaptive capacity and identification of adaptive measures in reducing the vulnerability. The analysis was descriptive and focused on potential coping mechanisms.

Paper 61	Spatial vulnerability assessments of rural households to climate change in Nigeria: Towards evidence-based adaptation policies	Madu	2012	No	Assessed district level vulnerability comparing urban and rural areas of Nigeria. Performed cluster analysis and identified determinants of each level of vulnerability. Focus was on adaptive actions and policy needs.
Paper 62	Climate Change and Vulnerability to Food Insecurity among Smallholder Farmers: A Case Study of Gweru and Lupane Districts in Zimbabwe	Mtswangwa	2011	Yes	This study assesses the vulnerability of smallholder farmers in two districts of Zimbabwe by assessing the likelihood of individual households being food insecure. The study assesses how households' own production levels interact with household characteristic. Regression carried out to determine significant factors with cereal production.
Paper 63	Measuring Household Food Vulnerability: Case Evidence from Northern Mali	Christiaensen	2000	No	Develop a methodology to analyze and measure household food vulnerability, defined as the probability now of caloric shortfall in the future.
Paper 64	Measuring Vulnerability and Poverty Estimates for Rural India	Gaiha	2008	No	Assessment of the vulnerability of rural households using panel data was made with ex ante and ex post measures of vulnerability calculated using poverty based vulnerability framework and econometric methods. Aggregate idiosyncratic and poverty components were calculated.
Paper 65	The Impact of Drought on Household Vulnerability: The Case of Rural Malawi	Makoka	2008	No	Econometric approach to analyzing household vulnerability. Methods were descriptive and not analytical.
Paper 66	Quantifying Vulnerability to Poverty: A Proposed Measure, with Application to Indonesia	Pritchett	2000	No	Quantified vulnerability to poverty. The outcomes, although quantified by the econometric model didn't show a clear methodological approach to differentiate determinants beyond the two data sets used.

Paper 67	Vulnerability assessment if the climate risks in the lower Songkhram River Basin,Thailand	UNDP	2007	No	No evaluation methodology applied and results were descriptive.
Paper 68	Village vulnerability assessment and climate change adaptation planning (V&A) Mlingotini & Kitonga, Bagamoyo district, Tanzania	Tobey	2011	No	Range of data collection but descriptive analysis of results.
Paper 69	Farmer Vulnerability Amidst Climate Variability: A case study of Dry Zone of Myanmar	Kyi	2012	No	Did not utilize data collection / secondary sources of data or an applied set of methods to describe vulnerability outcomes.
Paper 70	Climate change impacts on livelihood, vulnerability and coping mechanisms. A case study of West-Arsi Zone, Ethiopia.	Senbeta	2009	No	Vulnerability groupings were made with no clear empirical rationale.
Paper 71	Stakeholders' views in reducing rural vulnerability to natural disasters in Southern Mexico: Hazard exposure and coping and adaptive capacity	Saldana-Zorilla	2008	No	Multiple methods of data collection, but analysis was focused on coping responses and methods to reduce vulnerability, rather than the determinants in the surveyed communities.

Annex 4: Summary of final studies in quality review

Reference	Title	Included through
(Antwi-Agyei et al. 2013)	Characterising the nature of household vulnerability to climate variability: empirical evidence from two regions of Ghana	Literature search
(Baca et al. 2014)	An Integrated Framework for Assessing Vulnerability to Climate Change and Developing Adaptation Strategies for Coffee Growing Families in Mesoamerica	Expert recommendation
(Berkes and Ross, 2013)	Community Resilience: Toward an Integrated Approach	Expert recommendation
(Bogale, 2012)	Land ownership and conflicts over the use of resources: Implication for household vulnerability in eastern Ethiopia	Literature search
(Calvo and Dercon 2013)	Vulnerability to individual and aggregate poverty	Literature search
(Capaldo et al. 2010)	A model of vulnerability to food insecurity	Literature search
(CARE 2009)	Climate Vulnerability and Capacity Analysis: Handbook	Literature search
(Chhihn and Poch 2012)	Climate Change Impacts on Agriculture and Vulnerability as Expected Poverty of Kampong Speu Province, Cambodia	Literature search
(Dasgupta and Baschieri 2010)	Vulnerability to Climate Change in rural Ghana: Mainstreaming climate change in poverty-reduction strategies	Literature search
(Deressa, Hassan, and Ringler 2009)	Assessing Household Vulnerability To Climate Change: The Case Of Farmers In The Nile Basin Of Ethiopia	Literature search
(Eakin, Winkels, and Sendzimir 2009)	Nested vulnerability: exploring cross-scale linkages and vulnerability teleconnections in Mexican and Vietnamese coffee systems	Literature search
(Eakin et al. 2012)	Livelihoods and landscapes at the threshold of change: disaster and resilience in a Chiapas coffee community	Expert recommendation
(Échevin 2011)	Characterizing poverty and vulnerability in rural Haiti: a multilevel decomposition approach	Literature search
(Ford and Smit 2004)	A Framework for Assessing the Vulnerability of Communities in the Canadian Arctic to Risks Associated with Climate Change	Expert recommendation
(Füssel and Klein 2006)	Climate change vulnerability Assessments: An evolution of conceptual thinking	Expert recommendation
(Gandure et al., 2013)	Farmers' perceptions of adaptation to climate change and water stress in a South African rural community	Literature search
(Günther and Harttgen 2009)	Estimating Households Vulnerability to Idiosyncratic and Covariate Shocks: A Novel Method Applied in Madagascar	Literature search
(Hahn, Riederer, and Foster 2009)	The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique	Literature search
(Ionesco et al. 2009)	Towards a Formal Framework of Vulnerability to Climate Change	Expert recommendation
(Jamir et al. 2013)	Farmers' vulnerability to climate variability in Dimapur district of Nagaland, India	Literature search
(Khan, 2012)	A simple human vulnerability index to climate change hazards for Pakistan	Literature search

(Luers et al. 2003)	A method for quantifying vulnerability, applied to the agricultural system of the Yaqui Valley, Mexico	Literature search
(Marshall, 2010)	Understanding social resilience to climate variability in primary enterprises and industries	Expert recommendation
(Mengistu, 2011)	Farmers' perception and knowledge of climate change and their coping strategies to the related hazards: Case study from Adiha, central Tigray, Ethiopia	Literature search
(Misselhorn 2005)	What drives food insecurity in southern Africa? a meta-analysis of household economy studies	Literature search
(Mubaya et al. 2012)	Climate variability and change or multiple stressors? Farmer perceptions regarding threats to livelihoods in Zimbabwe and Zambia	Literature search
(Mutsvangwa 2011)	Climate Change and Vulnerability to Food Insecurity among Smallholder Farmers: A Case Study of Gweru and Lupane Districts in Zimbabwe	Literature search
(Nkondze, Masuku, and Manyatsi 2013)	Factors Affecting Households Vulnerability to Climate Change in Swaziland: A Case of Mpolonjeni Area Development Programme (ADP)	Literature search
(Notenbaert et al. 2013)	Derivation of a household-level vulnerability index for empirically testing measures of adaptive capacity and vulnerability	Literature search
(Piya, Maharjan, and Joshi 2012)	Vulnerability of rural households to climate change and extremes: Analysis of Chepang households in the Mid-Hills of Nepal	Literature search
(Sallu, Twyman, and Stringer 2010)	Resilient or Vulnerable Livelihoods? Assessing Livelihood Dynamics and Trajectories in Rural Botswana	Literature search
(Sarris and Karfakis 2010)	Vulnerability to Covariate and Idiosyncratic Shocks and Safety Net Targeting of Rural Households with an Application to Rural Tanzania	Literature search
(Sietz, Choque, and Lüdeke 2012)	Typical patterns of smallholder vulnerability to weather extremes with regard to food security in the Peruvian Altiplano	Literature search
(Tesso, Emana, and Ketema 2012)	Analysis of vulnerability and resilience to climate change induced shocks in North Shewa, Ethiopia	Literature search
(Westerhoff and Smit 2009)	The rains are disappointing us: dynamic vulnerability and adaptation to multiple stressors in the Afram Plains, Ghana	Literature search

Annex 5: Report of uniform and discreet retained frameworks

Report of uniform and discreet Frameworks (retained frameworks)			
Framework	Description	Main constructs	Articles
IPCC	This framework is guided by the definition and theory of the IPCC, which conceives of vulnerability to climate change as having three dimensions: Exposure to climate-induced shocks (a natural science phenomenon); the Sensitivity of the unit of analysis to such shocks (a social and natural science phenomenon); the adaptive capacity to deal with such shocks (a social science phenomenon). The framework often but not always creates a context-specific index of vulnerability from indicators of these three dimensions.	Vulnerability (IPCC); Exposure; Sensitivity Adaptive Capacity	Antwi-Agyei et al (2013); Baca et al (2014); CARE (2009); Fussel & Klein (2006); Hahn et al (2009); Ionesco et al (2009); Jamir et al (2013); Luers et al (2013); Notenbaert et al (2013); Piya et al (2012).
Vulnerability as Expected Poverty	This framework conceives of vulnerability as the potential of a unit of analysis (usually a household) becoming or remaining poor in the future. It is an econometric approach that makes forward projections based on cross-sectional data and associated risks of climatic (and sometimes non-climatic) stress. In some cases, assessments of vulnerability based on expected poverty are then regressed against a series of socio-economic data to identify determinants of vulnerability. There are two notable developments of this approach. The first focusses on a household's current and projected future *food security* status as opposed to *poverty* measured as income or consumption expenditure. The second variant is characterised by its inclusion of multi-level analysis. That is, projections are made for units of analysis at two different scales (usually household and	Vulnerability as Expected Poverty; Poverty; Food insecurity; Expected future food security status; Future nutritional status; Idiosyncratic shocks; Covariate shocks; Household level; Community level	Calvo & Dercon (2012); Chhinh & Poch (2012); Deressa et al (2009); Sarris & Karfakis (2010); Capaldo et al (3020); Mutsvangwa (2011); Echevin (2011); Günther & Harttgen (2009)

	community/local), and analysis is done of differences between units at different scales.		
Perceptions of climate change	This category constitutes less a coherent framework and more of a collection of studies whose approach differs significantly from the majority of studies in this review in terms of epistemological orientation and position on the intervention cycle. A tentative general description of this category is that the approach focusses on articulating perceptions of people whose livelihoods are affected by climate change (often farmers), and in particular their perceptions of climate change as a physical phenomenon, perceptions of the impact climate change has on their livelihoods, and respondent reported strategies of coping or adaptation.	Farmer perceptions; Adaptation strategy; Coping strategy	Gandure et al (2013); Mengitsu (2011); Mubaya (2012); Westerhoff & Smit (2009)
Asset vulnerability (Residual)	This framework conceives of household vulnerability to climate change in terms of the management control that can be exercised over a series of assets. These assets include labour, human capital, non-labour productive assets, household relations, and social capital. A vulnerability index is created through a framework of weighted indicators representing each type of asset.	Household vulnerability to climate change; Asset vulnerability; Future exposure; Communities at risk of climate shocks; Welfare of rural households; Prepared for adverse consequences	Dasgupta & Baschieri (2010)
Nested Vulnerability (Residual)	This framework is concerned with 'teleconnections' between households in geographically distant localities. It examines the mechanisms through which smallholders in distinct geographical contexts respond differently to exogenous shocks (climatic or not-climatic) and in so doing create a new set of influences on distant locations through connections in a nested globally interconnected	Livelihood vulnerability (B); Nested and teleconnected livelihood vulnerability; Nested system;	Eakin et al (2008)

	system.	Cross scalar teleconnections; Exogenous drivers; Response outcomes	
Current and future vulnerability (Residual)	The main characteristics of this framework is its comparison of current and future states of vulnerability. Vulnerability is conceived as being composed of two principal elements: exposure to climatic changes, and adaptive capacity. Multiple data sources are used to generate an assessment of current exposure and current adaptive capacity. On the basis of this data, and on historical social and physical trends, projections are made as to likely future states of exposure and future states of adaptive capacity.	Vulnerability to climate risks; Current vulnerability; Future vulnerability; Current adaptive capacity; Exposure; Future exposure	Ford & Smit (2004)
Livelihood vulnerability index (Residual)	This framework consists of an index to measure levels of vulnerability. The index is composed of a highly developed set of household-level indicators chosen to represent seven dimensions of a particular conception of 'livelihoods'. These seven dimensions are: socio-demographic profile; livelihood strategies; social network; health; food; water; and natural disaster and climate change.	Livelihood vulnerability (A); Livelihood strategies; Health; Socio-demographic profile; Water; Natural disaster and climate change	Hahn et al (2009)
Intensifying vulnerability to food insecurity (Residual)	Vulnerability is situated in a recursive framework which captures a cyclical nature of intensification of vulnerability principally through the negative impacts that coping strategies can have on food security. Vulnerability is conceived principally in terms of food security, which	Livelihood level issues; Access to sufficient food; Food insecurity;	Misselhorn (2005)

	in turn is conceived in terms of access to food and food productivity. When food security is negatively impacted through climatic and non-climatic drivers, vulnerable households and communities respond with particular coping strategies, which can have a recursive effect on future levels of food security.	Household and community vulnerability; Livelihood strategies; Direct drivers	
Nkondze et al (2013) (Residual)	At a very general level, this framework investigates factors affecting household vulnerability. An index is constructed through which to measure vulnerability, which is then analysed against socio-economic data to determine the most significant factors influencing levels of household vulnerability.	Factors affecting vulnerability; Household vulnerability to climate change	Nkondze et al (2013)
Patterns of smallholder vulnerability (Residual)	Cluster pattern analysis is employed in this framework to investigate whether there are, and which, characteristics that explain the causal structure of vulnerability to weather extremes. A measure of household/smallholder vulnerability is created using a combination of IPCC and Food Security household-level indicators. A cluster pattern analysis is then run relating measures of vulnerability to socio-economic and other household-level data to identify characteristics, and in particular combinations of characteristics that are related to concentrations of vulnerability.	Vulnerability IPCC; Exposure; Sensitivity; Adaptive capacity; Cluster patter analysis; Food security	Sietz et al (2012)
Livelihood trajectories and resilience and vulnerability (Residual)	On the basis of a mixed methods data collection methodology, the concept of 'livelihood trajectories' is explored among households over a period of (in this case) 30 years. With this long term approach, the framework seeks to generate narrative accounts of which livelihood strategies and trajectories lead to resilient and vulnerable states.	Resilience and vulnerability of rural livelihoods; Livelihood trajectories; Dynamic natural resource base; Factors influencing resilience and vulnerability	Sallu et al (2010)

Determinants of Resilience (Residual)	The focus is on identifying determinants of resilience to climate-related shocks. Resilience is conceptualised temporally in terms of the time taken to make a recovery after being impacted by shocks. A vulnerability index (in this case based on the framework of the IPCC) is created to compute measures of vulnerability based on household survey data. Classifications of resilience are then created based on the time taken to return to pre-shock states, which are then analysed against the vulnerability data to identify determinants of resilient households.	Vulnerability IPCC; Determinants of Resilience; Household level resilience; Exposure; Adaptive capacity;	Tesso et al (2012)

Annex 6: Report of uniform and discreet constructs from retained frameworks

Report of uniform and discreet constructs (retained frameworks)		
Construct	Definitions	Article
Vulnerability (IPCC);	"For our methodology, vulnerability is defined as changes in climate variables that affect agricultural and natural systems over a timeframe. The vulnerability in the livelihoods of small coffee farmers is a function of three factors: exposure, sensitivity and adaptive capacity."	Baca et al 2014
	"The degree to which a system is susceptible to, or 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 variation to which a system is exposed, its sensitivity, and its adaptive capacity.5"	CARE 2009
	The concept of vulnerability is closely linked to that of resilience; however, the concepts emerged from different disciplinary traditions and have distinct applications, with implications for the utility of these concepts for different units of analysis (Eakin and Luers 2006; Turner 2010). Vulnerability generally refers to the propensity of some unit of exposure to experience harm. In practice, house-holds are often a convenient unit of analysis for vulnerability assessments that aim to differentiate a population in terms of sensitivity to a particular stressor and capacities to effectively respond (Eakin and Luers 2006). At the household level, vulnerability is often evaluated by assessing exposure (the physical relation of the household to a stressor) and sensitivities to the losses experienced (e.g., what the impact means for the household's function and survival), as well as by the households' ability to cope and adapt, or its ''adaptive capacity,'' prior to and after experiencing loss.	Eakin et al 2012
	Vulnerability: The degree to which a system is susceptible to, or 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 variation to which a system is exposed, its sensitivity, and its adaptive capacity.	Fussel & Klein 2006
	Many of these rely heavily on the IPCC working definition of vulnerability as a function of exposure, sensitivity, and adaptive capacity (IPCC, 2001).	Hahn et al 2009
	As per the IPCC's definition and framework, vulnerability is understood as a function of three components—exposure, sensitivity and adaptive capacity. Vulnerability is defined as ''the degree to which a system is susceptible to or unable to cope with, adverse effects of climate change,	Jamir et al 2013

	including climate variability and extremes'' (IPCC 2001).	
	we derive a generic vulnerability metric by translating a general definition of vulnerability, the susceptibility to damage, into a mathematical expression. To do this we first define a threshold of damage and then measure susceptibility in terms of the system's sensitivity to and exposure to stressors. We then propose a framework for estimating a system's ability to modify its vulnerable conditions by adapting and responding to changing circumstances.	Luers et al 2003
	For the purpose of this paper, we work with the definition proposed by the Working Group II of the IPCC in the third assessment report. We will refer to (1) exposure to climate change impacts, (2) sensitivity to those impacts and (3) the capacity to cope with those impacts as the components of vulnerability. Vulnerability is thus comprised of risks (or a chain of risky events) that people confront in pursuit of their livelihoods, the sensitivity of the livelihood to these risks, the risk response or the options that people have for managing these risks and finally the outcomes that describe the loss in well-being (Turner et al. 2003).	Notenbaert et al 2013
	Following the definition of vulnerability given by IPCC (2001), vulnerability in this study is taken to be a function of exposure, sensitivity, and adaptive capacity.	Piya et al 2012
	Climate vulnerability is considered as a function of exposure, sensitivity and coping/adaptive capacity (IPCC 2007).	Sietz et al 2012
	Therefore, vulnerability is the degree to which a system is susceptible or unable to cope with the adverse effects of climate change, including climate variability and extremes. In this regard, vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity [4].	Tesso et al 2012
	Nevertheless, the most commonly accepted approach, which is the approach adopted in this paper, comes from the Intergovernmental Panel on Climate Change (IPCC)'s definition of vulnerability (to climate change) where vulnerability is ''the degree to which an environmental or social system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes''	Antwi-Agyei et al 2013
Exposure	Exposure is the nature and extent of changes that a place's climate is subjected to with regard to variables such as temperature, precipitation, and extreme weather events.	Baca et al 2014
	Exposure is a property of a community relative to climatic conditions. It reflects both the nature of the climatic conditions and nature of the community itself. Some communities may be exposed to a particular climate event whereas the same event may not affect another community. Climatic characteristics include magnitude, frequency, spatial dispersion, duration, speed of onset, and	Ford & Smit 2004

	temporal spacing of climatic risks, relating to temperatures, precipitation, and wind. The nature of the community concerns its location relative to the climatic risks	
	Exposure: The nature and degree to which a system is exposed to significant climatic variations. The exposure of a system to climate stimuli depends on the level of global climate change and, due to the spatial heterogeneity of anthropogenic climate change, on the system's location	Fussel & Klein 2006
	Exposure in this case is the magnitude and duration of the climate-related exposure such as a drought or change in precipitation,	Hahn et al 2009
	Asper the IPCC's definition and framework, vulnerability is understood as a function of three components—exposure, sensitivity and adaptive capacity. Vulnerability is defined as ''the degree to which a system is susceptible to or unable to cope with, adverse effects of climate change, including climate variability and extremes'' (IPCC 2001).	Jamir et al 2013
	Different communities and ecosystems are exposed to varying magnitudes and frequencies of disturbing forces, often resulting in differential vulnerabilities (IPCC, 2001; Turner et al., 2003a, b). We capture these differences in exposure by calculating the expected value of the ratio of sensitivity to the state relative to a threshold based on the frequency distribution of the stressors of concern.	Luers et al 2003
	risks (or a chain of risky events) that people confront in pursuit of their livelihoods, (Turner et al. 2003).	Notenbaert et al 2013
	Exposure is the nature and degree to which a system is exposed to significant climatic variations.	Piya et al 2012
	exposure, sensitivity and coping/adaptive capacity (IPCC 2007).	Sietz et al 2012
	Furthermore, in the IPCC frame- work, exposure has an external dimension, whereas both sensitivity and adaptive capacity have an internal dimension, which is implicitly assumed in the integrated vulnerability assessment framework [13].	Tesso et al 2012
	Exposure relates to the extent to which a particular system may be exposed to climatic stresses or variations (IPCC 2007).	Antwi-Agyei et al 2013
Sensitivity	sensitivity determines the response of a given system to climate change and may be shaped by socioeconomic and ecological conditions of the system (IPCC 2007).	Antwi-Agyei et al 2013
	Sensitivity is a measure of how systems could be affected by the change in climate (e.g. how much crop yields change or how much human health might be affected).	Baca et al 2014
	Sensitivity: The degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. [...] The effect may be direct [...] or indirect [...]	Fussel & Klein 2006

	[...] The sensitivity of a system denotes the (generally multi-factorial and dynamic) dose – response relationship between its exposure to climatic stimuli and the resulting impacts.	
	sensitivity is the degree to which the system is affected by the exposure	Hahn et al 2009
	As per the IPCC's definition and framework, vulnerability is understood as a function of three components—exposure, sensitivity and adaptive capacity. Vulnerability is defined as ''the degree to which a system is susceptible to or unable to cope with, adverse effects of climate change, including climate variability and extremes'' (IPCC 2001).	Jamir et al 2013
	is the degree to which a system is affected, either adversely or beneficially by climate-related stimuli.	Piya et al 2012
	We consider the effects of weather disturbance on the agricultural systems as sensitivity.	Sietz et al 2012
Adaptive Capacity	Adaptive capacity in the context of climate change has been defined by the IPCC (2007, p. 869) as ''the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.'' Adaptive capacity connotes some positive attributes of a system that enable it to reduce the adverse impacts (vulnerability) associated with climate change (Engle 2011).	Antwi-Agyei et al 2013
	In contrast, adaptive capacity is defined as a system's ability to adjust to climate change in order to reduce or mitigate possible damage [3]. Adaptive capacity is dynamic, and depends partly on the society productive base, such as: natural and artificial assets, social benefits and networks, human capital and institutions, governance, national income, health and technology [2], and how much capability a society has to adapt to the changes so as to maintain, minimize loss of, or maximize gain in welfare.	Baca et al 2014
	Adaptive capacity is the capacity of actors in a system to influence resilience (Folke et al. 2010), and often works through social networks and learning communities (Goldstein 2012). [...] We view adaptive capacity as a latent property, which can be activated when people exercise their agency. The processes by which this occurs have not been well explored.	Berkes & Ross 2013
	The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.	CARE 2009
	Adaptive capacity: The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with	Fussel & Klein 2006

	the consequences.	
	adaptive capacity is the system's ability to withstand or recover from the exposure (Ebi et al., 2006).	Hahn et al 2009
	Asper the IPCC's definition and framework, vulnerability is understood as a function of three components—exposure, sensitivity and adaptive capacity. Vulnerability is defined as ''the degree to which a system is susceptible to or unable to cope with, adverse effects of climate change, including climate variability and extremes'' (IPCC 2001).	Jamir et al 2013
	We define adaptive capacity as the extent to which a system can modify its circumstances to move to a less vulnerable condition (Fig. 1c). We quantify adaptive capacity(A) as the difference in the vulnerability under existing conditions and under the less vulnerable condition to which the system could potentially shift: A = V (existing conditions) – V (modified conditions)	Luers et al 2003
	It refers to the ability of individuals or communities to adapt to adversity and stressful life-events by 'reorganising' through networks or institutions that learn, store knowledge and experience and are creative, flexible and novel in their approach to problem solving (Vayda and McCay, 1975; McCay, 1981; Sonn and Fisher, 1998).	Marshall 2010
	Adaptive capacity is the ability of a system to adjust to climate change including climate variability and extremes, to moderate the potential damage from it, to take advantage of its opportunities, or to cope with its consequences. Selection of indicators for adaptive capacity is based on the DFID sustainable livelihoods framework, whereby adaptive capacity is taken to be a function of asset possession by the households (Jakobsen, 2011; Nelson, et al., 2010b).	Piya et al 2012
	the adaptive capacity of smallholders (the term as used in this study encompasses the coping capacity) describes the ability to adjust to weather extremes, manage damages or explore alternative livelihood opportunities.	Sietz et al 2012
	According to Füssel and Klein, the risk-hazard framework (biophysical approach) corresponds most closely to sensitivity in the IPCC terminology while the adaptive capacity (broader social development) is largely consistent with the socioeconomic approach [18]. [...] In the framework, capacity is generated from the implementation of adaptation and mitigation interventions [18].	Tesso et al 2012
Vulnerability as	In this article, we explore the notion of vulnerability to poverty, closely linked with the magnitude	Calvo & Dercon

Expected Poverty;	of the threat of poverty, measured ex-ante, before uncertainty has been resolved. [...] To clarify how all these intuitions come together under the concept of vulnerability, this paper proposes an axiomatic approach to the measurement of both individual and aggregate vulnerability.	2013
	Household vulnerability as expected poverty is defined as the probability that households will move into poverty given certain environmental shocks, current poverty status and household characteristics of respondents.	Chhihn & Poch 2012
	Thus, vulnerability is seen as expected poverty, while consumption (income) is used as a proxy for well-being. [...] This method is based on estimating the probability that a given shock or set of shocks will move household consumption below a given minimum level (such as a consumption poverty line) or force the consumption level to stay below the minimum if it is already below this level (Chaudhuri et al. 2002).	Deressa et al 2009
	we can define vulnerability to poverty as the probability of falling into poverty when one's consumption/income falls below a predefined poverty line.	Echevin 2011
	The suggested approach is an integration of multilevel analysis (e.g., Goldstein, 1999) into Chaudhuri's (2002) method to estimate vulnerability	Günther & Harttgen 2009
	vulnerability as a starting point which focuses on the susceptibility of the household (Füssel., 2007). This study takes on the starting point interpretation, which takes the root problem as social vulnerability and examines the current vulnerability of the households as a measure of vulnerability to climate change. Households that are currently vulnerable to food insecurity will find it difficult to cope with adverse impacts of changes in climatic conditions. Thus measuring the likelihood of being food insecure provides a way to examine vulnerability to climate change. [...] Vulnerability refers to the manner and degree to which a system is susceptible to conditions that negatively affect the well-being of the system. In the climate change field, the IPCC Third Assessment Report defines vulnerability as "the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes" (McCarthy et al., 2001). [...] The differences between these two interpretations of vulnerability are summarized in Table 1.	Mutsvangwa 2011

	Vulnerability according to the end point interpretation represent the expected net impacts of a given level of global climate change, taking into account feasible adaptations. Vulnerability according to the starting point interpretation focuses on reducing internal socioeconomic vulnerability to any climatic hazard. This study takes on the starting point interpretation.	
	Thus a household is said to be vulnerable to the outcome of a risk event, if it does not have sufficient resources to adequately contend with the risk event. In other words, the extent to which a household is vulnerable to a risk event, namely the extent to which the household can become and/or remain poor or food deprived, depends on the size of the risk event and how effective the household is in managing the risk event. [...] considers vulnerability as the probability of consumption falling below a poverty threshold (Christiaensen and Subbarao 2004, Chaudhuri, et. al. 2002),	Sarris & Karfakis 2010
Poverty	Our aim is merely to make an ex-ante statement on the vulnerability of the individual to fall below a poverty norm z,	Calvo & Dercon 2013
	This study adopts the approach to measuring household economic vulnerability posited and elaborated in Chaudhuri's (2003) study of household vulnerability [...] Technically, the household vulnerability index is derived from the difference between the expected log per capita income and the minimum log per capita income threshold, with households having per capita incomes lower than the minimum per capita income defined as vulnerable (poor). The expected log per capita income is estimated using the three-step feasible generalised least squares (FGLS) method.	Chhihn & Poch 2012
	a given minimum level (such as a consumption poverty line)	Deressa et al 2009
	consumption falling below a poverty threshold (Christiaensen and Subbarao 2004, Chaudhuri, et. al. 2002)	Sarris & Karfakis 2010
Food insecurity;	Food insecurity in the communities described by the case studies maybe conceptualized as one element in an entrenched and escalating cycle of vulnerability (Fig. 3).	Misselhorn 2005
Expected future food security status;	conceptual framework drawn from it by Løvendal and Knowles (2005).	Capaldo et al 2010

Future nutritional status	conceptual framework drawn from it by Løvendal and Knowles (2005).	Capaldo et al 2010
Idiosyncratic shocks;	Households in developing countries are frequently hit by severe idiosyncratic and covariate shocks resulting in high income volatility. [...] 1. Here, and in the following, idiosyncratic shocks refer to household- specific shocks (e.g., injury, birth, death, or job loss of a household member) that are only weakly correlated across households within a community. Covariate shocks refer to shocks that are correlated across households within communities but only weakly correlated across communities (e.g., natural disasters or epidemics).	Günther & Harttgen 2009
Covariate shocks;	Households in developing countries are frequently hit by severe idiosyncratic and covariate shocks resulting in high income volatility. 1 [...] 1. Here, and in the following, idiosyncratic shocks refer to household- specific shocks (e.g., injury, birth, death, or job loss of a household member) that are only weakly correlated across households within a community. Covariate shocks refer to shocks that are correlated across households within communities but only weakly correlated across communities (e.g., natural disasters or epidemics).	Günther & Harttgen 2009
Household level;	an extension of this empirical framework will consist in using two-level (i.e. household and community levels) modelling of the impact of those shocks following Günther and Harttgen (2009)'s approach.	Echevin 2011
	Multilevel models are designed to analyze the relationship between variables that are measured at different hierarchical levels (for an introduction see, e.g., Bryk & Raudenbush, 1992; Goldstein, 1999; Hox, 2002). We speak of ''hierarchical" or ''multilevel" data structure whenever variables are collected at different hierarchical levels with lower-levels (e.g., house- holds) nested within higher-levels (e.g., communities).	Günther & Harttgen 2009
Community level	an extension of this empirical framework will consist in using two-level (i.e. household and community levels) modelling of the impact of those shocks following Günther and Harttgen	Echevin 2011

	(2009)'s approach.	
	Multilevel models are designed to analyze the relationship between variables that are measured at different hierarchical levels (for an introduction see, e.g., Bryk & Raudenbush, 1992; Goldstein, 1999; Hox, 2002). We speak of ''hierarchical" or ''multilevel" data structure whenever variables are collected at different hierarchical levels with lower-levels (e.g., house- holds) nested within higher-levels (e.g., communities).	Günther & Harttgen 2009
Farmer perceptions;	Unique in our study, is the use of individual perceptions in identifying and understanding the processes of adaptation in an area that has undergone significant political and socio-economic reformation resulting from a series of conflicts over land resources.	Gandure et al 2013
	there is an alternative approach which underscores how individuals perceive their environment and make decisions, with mal-adaptations attributed to problems in perception, cognition or the lack of available information (Diggs, 1991; Saarinen, 1966; Taylor et al., 1988). The main point is that from whatever level these adaptation measures are taken, the adaptation and coping measures depend on households' perceptions of extreme events and the problems associated with them (Davies, 1993).	Mubaya et al 2012
Adaptation strategy;	In this paper, we document household responses to a climatic shock, Stan, to gain insight into how natural resource- dependent communities move to secure their livelihoods following significant loss, the implications of household responses for coffee farming as a ''domain of attraction,'' as well as to highlight those aspects of household choices and perceptions that may be indicative of resilience at broader scales.	Eakin et al 2012
	Adaptations, or adaptive strategies, employed by individuals or groups are depicted as being mediated through their relative adaptive capacities, indicating that adaptations may or may not be accessed according to the distribution of various types of resources such as physical or social capital, as developed by Adger and Kelly (1999).	Westerhoff & Smit 2009
Asset vulnerability;	Using Moser's (1998) asset vulnerability framework as guidance, we selected a range of variables to create an index of household vulnerability from GLSS 4. Each variable captures an aspect of vulnerability.	Dasgupta & Bashieri 2010
Livelihood	By placing the household as the focus of analysis, livelihood approaches highlight both the	Eakin et al 2009

vulnerability (B);	exogenous drivers (i.e. the risk and stress factors) and the factors internal to the household (i.e. ability to mitigate and cope with stress) which together influence household security and well-being (Chambers and Conway, 1992; Ellis, 1998).	
Nested and teleconnected livelihood vulnerability;	In this article we use the concept of ‘‘nested and teleconnected vulnerabilities’’ to illustrate how the vulnerabilities and responses of farm households in distinct geographic locations are linked through cross-scalar processes, as well as ‘‘teleconnected’’ in space and time. In a nested system, profound changes in key variables that operate normally only at one level, e.g., within a defined geographic region or administrative domain, can have non-linear outcomes for processes operating at broader scales of analysis (Gunderson and Holling, 2001).	Eakin et al 2009
Nested system;	In a nested system, profound changes in key variables that operate normally only at one level, e.g., within a defined geographic region or administrative domain, can have non-linear outcomes for processes operating at broader scales of analysis (Gunderson and Holling, 2001). Local level processes can episodically influence larger scale phenomena, and such explosive ‘‘upward cascades’’ can be sources of surprise at distant locations.	Eakin et al 2009
Cross scalar teleconnections;	‘‘teleconnections’’, a term used in climatology in relation to ‘‘any transmission of a coherent effect beyond the location where the forcing occurred’’ (Chase et al., 2005). For example, one of the teleconnections associated with the El Nino-Southern Oscillation effect is severe drought in Northeastern Brazil. Teleconnections are also associated with other climate phenomena such as the North Atlantic Oscillation. The label of ‘‘teleconnection’’ is not explanatory in and of itself, but rather signifies the existence of a correlation in events, and highlights the need to explore the connecting mechanisms and drivers in order to anticipate outcomes.	Eakin et al 2009
Exogenous drivers;	exogenous drivers (i.e. the risk and stress factors)	Eakin et al 2009
Response outcomes	outcomes of these responses in terms of individual or household welfare.	Eakin et al 2009
Vulnerability to climate risks;	The conceptual model of community vulnerability to climate change outlined here builds on the literature, conceptualizing vulnerability as a function of exposure of the community to climate-change effects and its adaptive capacity to deal with that exposure. [...]	Ford & Smit 2004

	A research framework for empirically applying the model of vulnerability proposed above to Arctic communities is illustrated in Figure 3. The first stage assesses current vulnerability by documenting current exposures and current adaptive strategies. The second stage assesses future vulnerability by estimating directional changes in exposure and predicting future adaptive capacity on the basis of past behavior.	
Current vulnerability;	The assessment of current vulnerability requires analyzing and documenting communities' experiences with climatic risks (current exposure) and the adaptive options and resource management strategies employed to address these risks (current adaptive capacity).	Ford & Smit 2004
Future vulnerability;	Future vulnerability is assessed by analyzing how cli- mate change will alter the nature of the climate-related risks and whether the communities' coping strategies will have the capacity to deal with these risks. Assessing future exposure involves collaboration with the climate science community to estimate the likelihood of changes in climatic attributes identified by the community	Ford & Smit 2004
Current adaptive capacity;	Adaptive capacity refers to a community's potential or ability to address, plan for, or adapt to exposure (Smit and Pilifosova, 2003). Most communities can cope with normal climatic conditions and a range of deviations around norms. People have learned to modify their behaviour and their environment to manage and take advantage of their local climatic conditions (Jones and Boer, 2003). This ability to cope is referred to in the literature as the "coping range"; it reflects resource use options and risk management strategies to prepare for, avoid or moderate, and recover from exposure effects (Hewitt and Burton, 1971; Smit et al., 1999; Jones, 2001; Smit and Pilifosova, 2003). Adaptive capacity relates to communities' resilience, resistance, flexibility, and robustness (Smithers and Smit, 1997). It is influenced by economic wealth, social networks, infrastructure, social institutions, social capital, experience with previous risk, the range of technological adaptation available, and equity of access to resources within the community, as well as by other stresses that contribute to the environment in which decisions are made (Adger and Kelly, 1999; Smit and Pilifosova, 2001; Smith et al., 2003).	Ford & Smit 2004
Future exposure	Future exposure also includes estimating the future state of the socioeconomic conditions, given that exposure is a property of the system relative to risk.	Ford & Smit 2004
Livelihood	The LVI includes seven major components: Socio-Demographic	Hahn et al 2009

vulnerability (A);	Profile, Livelihood Strategies, Social Networks, Health, Food, Water, and Natural Disasters and Climate Variability	
Livelihood strategies;	Household working elsewhere; agriculture dependent households; livelihood diversification	Hahn et al 2009
	A livelihood maybe described as the capability, assets and activities required for a means of living. People everywhere pursue a range of livelihood strategies in attempting to increase their income and asset base (‘accumulation strategies’), spread or reduce risk (in- crease security through ‘adaptive strategies’), mitigate the impact of shocks (‘coping strategies’), and at the extreme, ensure survival through ‘survival strategies’ (Devereux, 1999; Scoones, 2000).	Misselhorn 2005
Health;	Proximity to health facility; 2 weeks illness; malaria-exposure-prevention	Hahn et al 2009
Socio-demographic profile;	Dependency ratio; female headed households; uneducated headed households; households with orphans	Hahn et al 2009
Water;	Sub-constructs: water conflict; natural water source; proximity to water source; inconsistent water supply; inverse water storage	Hahn et al 2009
Natural disaster and climate change	Sub-constructs: flood, drought, cyclone events; no warning of disaster; injury or death from disaster; maximum temperature; minimum temperature; average precipitation	Hahn et al 2009
Household and community vulnerability;	In general terms, vulnerability and social resilience have been similarly defined as the ability of a system or community to resist or absorb adverse conditions. [...] Vulnerable communities, where people are unable to buffer themselves from hazards for a number of reasons, have a low ability to cope with short-term shocks (such as drought) and to mitigate chronic stressors, which in turn means that the negative impacts on livelihoods resulting from coping and survival strategies are very high.	Misselhorn 2005
Livelihood	A livelihood maybe described as the capability, assets and activities required for a means of living. People everywhere pursue a range of livelihood	Misselhorn 2005

strategies;	strategies in attempting to increase their income and asset base (‘accumulation strategies’), spread or reduce risk (in- crease security through ‘adaptive strategies’), mitigate the impact of shocks (‘coping strategies’), and at the extreme, ensure survival through ‘survival strategies’ (Devereux, 1999; Scoones, 2000).	
Cluster pattern analysis;	Without such a pre-selection, alternative approaches investigate the structure of the data space spanned by selected vulnerability indicators using cluster analysis. They deliver useful insights into recurrent indicator combinations based on similarities among units of analysis, in cases where such a grouping exists. For example, clustering revealed typical livelihood strategies employed by small- holders in Mexico and Botswana (Eakin 2005; Sallu et al. 2010).	Sietz et al 2012
Food security	Food security is often discussed in terms of four dimensions: food availability, access, stability of supply/ access and utilisation (FAO 2000).	Sietz et al 2012
Resilience and vulnerability of rural livelihoods;	Fraser et al.’s (2010) vulnerability framework	Sallu et al 2010
Livelihood trajectories;	Bagchi et al. (1998) use the term “livelihood trajectories” to describe and explain the direction and pattern of livelihoods of individuals or groups of people (e.g., households). A livelihood trajectory approach allows the examination of an individual household’s “strategic behavior that is embedded in a historical repertoire, in social differentiation” (de Haan and Zoomers 2005), and in perceptions of risk. Such an approach is sensitive to life histories (an individual’s own “story” of their changing livelihoods).	Sallu et al 2010
Factors influencing resilience and vulnerability	Through comparative research we provide a rich contextual narrative and use it to explore those factors that in isolation and combination push livelihoods along particular “trajectories” towards vulnerability or resilience.	Sallu et al 2010
Determinants of Resilience;	important determinants for resilience at household level in North Shewa zone of Ethiopia.	Tesso et al 2012

Household level resilience;	According to DFID, resilience at community level is explained as the ability of countries, communities and households to manage change, by maintaining or transforming living standards in the face of shocks or stresses—such as earthquakes, drought or violent conflict—without compromising their long- term prospects [10]. Similarly, resilience is the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change. This is a measurement of community's capacity to absorb external shocks. In the aftermath of occurrence of climate change induced shocks, how do farmer bounce back to normal livelihood is about the resilience level of farming com- munity. A resilient community is able to respond to changes or stress in a positive way, and is able to maintain its core functions as a community despite those stresses [11].	Tesso et al 2012

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