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► To cite this version:

Adrien Comte, Linwood Linwood H. Pendleton, Denis Bailly, Emmanuelle Quillérou. Conceptual advances on global scale assessments of vulnerability: Informing investments for coastal populations at risk of climate change. *Marine Policy*, 2019, 10.1016/j.marpol.2018.10.038 . hal-01939769

HAL Id: hal-01939769

<https://hal.univ-brest.fr/hal-01939769v1>

Submitted on 9 Jan 2020

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Conceptual advances on global scale assessments of vulnerability: Informing investments for coastal populations at risk of climate change

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Abstract :

Since the 1990s, the Intergovernmental Panel on Climate Change (IPCC) has used global assessments of vulnerability to inform investment and action against the effects of climate change. Beyond the IPCC, others have undertaken global assessments to understand the vulnerability of coastal areas to climate change. Eight global vulnerability assessments are compared to understand similarities and differences in their results and the metrics used to construct a vulnerability index. Variations in objectives, conceptualizations of vulnerability, operationalization of the concepts, scope and depth of data drawn upon lead to contradictory rankings of priority areas for climate action between assessments. The increased complexity and scope of indicators make it difficult to untangle the root causes of such differences in rankings. It is also difficult to identify the degree to which climate change influences vulnerability rankings compared to other factors such as local environmental conditions and the capacity of populations to deal with environmental change. The way to undertake global assessments needs to be reshaped to better inform planning of international development along different objectives. Global level assessments need to be simplified and harmonized to better isolate the impact of climate change specific drivers. Decision-makers would make better use of such global assessments as scoping studies rather than expect comprehensive and robust priorities for investment. Such scoping studies can help target locations where supplementary, in-depth local analyses need to be conducted. At the local level, the possibility to collect context-specific information, particularly on adaptive capacity, allows the robust assessment of vulnerability.

Keywords : Climate change, Vulnerability, Marine and coastal areas, Prioritizing investments, Global assessments, Conceptual frameworks

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1. Global level assessments, climate change impacts on coastal populations and informed action

Climate change is expected to have severe adverse effects on marine and coastal ecosystems and human activities which depend on them (Allison & Bassett, 2015; Gattuso et al., 2015), thus calling for better identification of areas at particular risk to mitigate their impacts. Long-term changes, such as sea-level rise, ocean acidification, and changes in sea surface temperature are expected to put millions of people and billions of dollars' worth of economic sectors at risk (O. Hoegh-Guldberg et al., 2014). Countries across the globe are not equally vulnerable to, and will not be equally impacted by, the wide-ranging effects of climate change, the large majority of which is expected to be negative. Understanding which countries are most vulnerable to the adverse effects of climate change is important, firstly for equity

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59 reasons (Smit & Pilifosova, 2003; Wolff et al., 2015), and secondly to inform investments in research and
60 action including adaptation planning and capacity building (Cutter, Boruff and Shirley 2003).
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62 This issue is raised in article 4.4 of the United Nations Framework Convention on Climate Change
63 (UNFCCC). Article 4.4 states that developed countries shall “[...] assist the developing country parties
64 that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation to
65 those adverse effects” (United Nations, 1992). The same mandate was given to global financial
66 institutions such as the Green Climate Fund (GCF) and the Adaptation Fund. For instance, the GCF
67 “[aims] for a floor of fifty per cent of the adaptation [funding] allocation for particularly vulnerable
68 countries, including least developed countries (LDCs), small island developing States (SIDS) and African
69 States” (GCF, 2014, Decision B.06/06). In addition, international development targets such as the
70 Sustainable Development Goals (SDGs) have reinforced the demand for scientific assessments at the
71 global level that can help inform climate and development investment and action. The international
72 climate negotiations embraced the idea of vulnerability. The scientific community is attempting to
73 provide input to climate negotiations, but some argue that identifying vulnerable countries is a political
74 process (Klein, 2009). For instance, the Climate Vulnerable Forum was founded to create a coalition and
75 build capacity of countries that identify as vulnerable in international negotiations.
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80 Global level indicator-based vulnerability assessments have become very popular in the hope of using
81 them as tools to identify “developing country parties that are particularly vulnerable to the adverse
82 effects of climate change” to receive help from countries that have the means to do so, in the form of
83 financial transfers in order to “[meet the] costs of adaptation to those adverse effects” (United Nations,
84 1992). The Intergovernmental Panel on Climate Change (IPCC) was an early adopter of global level
85 indicator-based vulnerability assessments to identify vulnerable places in particular need of assistance to
86 combat climate change. They aimed at communicating the seriousness of climate change more
87 effectively with spatial analyses and maps. Vulnerability assessments are used by the IPCC to
88 communicate places needing investment and action the most.
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91 Assessing future threats of global environmental change on ocean and coastal socio-ecological systems is
92 important for the sustenance of economies and livelihoods. Vulnerability assessments developed by the
93 research community rely on a scientifically sound understanding of the impacts of climate change on
94 physical, ecological and social systems (Adger, 2006; Cutter et al., 2003; Polsky, Neff, & Yarnal, 2007;
95 Schröter, Polsky, & Patt, 2005; Turner et al., 2003). They draw from a range of academic disciplines
96 including oceanographic, ecological, and social sciences. They use different methods but usually
97 construct composite indicators to be able to rank countries (Tonmoy & Hinkel, 2014; Wolf, Hinkel,
98 Bisaro, & Klein, 2012). However, the current lack of understanding of the mechanistic relationships
99 between global changes and socio-economic impacts is hindering the development and establishment of
100 comprehensive and consistent approaches by the marine science community. It has been argued that
101 using the IPCC vulnerability framework could help the marine science community move forward to
102 better characterize impacts of climate change on the marine environment and guide decision-makers
103 (Mathis et al., 2015).
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115 Many studies coming from the research community as well as international organizations and Non-
116 Governmental Organizations (NGOs) have attempted to rank countries based on their vulnerability to
117 climate change. In order to do so, composite indexes have been built to establish these vulnerability
118 assessments. There is no unified approach to global indicator-based vulnerability assessment which has
119 resulted in a variety of applications, even for those focused specifically on marine and coastal
120 applications, and a drive for such analyses to become more data intensive and “comprehensive” over
121 time (Füssel & Klein, 2006). Methodologies and results vary greatly across these assessments, which
122 have triggered much debate within the research community on using indicator-based vulnerability
123 assessments at the global level. For example, Hinkel (2011) argues that vulnerability assessment was
124 originally designed and is best suited for application at the local level and not the global level.
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128 Acknowledging that different local vulnerability assessments can have different goals which inform the
129 types of methods and appropriate data (Preston, Yuen, & Westaway, 2011), there are inherent problems
130 in conducting vulnerability assessments at the global level. The assumptions and final scores used for
131 prioritizing countries produced by such assessments make it difficult to understand the main drivers of
132 climate vulnerability and thus identify the main opportunities for relevant climate-related investment.
133 Methodologies are rarely explicit, and aggregating all data used into a single score degrades complexity
134 and quality of information. The challenges that confront the global level application of vulnerability
135 assessments for use in targeting climate-related investment include:
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- 138 • a lack of harmonized conceptualization of vulnerability and associated concepts, in particular impact
139 and adaptive capacity, in addition to how these concepts are operationalized in practice,
- 141 • an ever expanding number of variables used for such assessments, many of which are not available
142 reliably at the global level, resulting in increased complexity of analysis and combination of very different
143 metrics together which make it difficult to isolate climate impacts on populations from other factors,
- 145 • a lack of consideration of the costs of action in addition to climate vulnerability and impacts.

147 Section 2 of this paper summarizes briefly the current use of vulnerability assessments to understand
148 impacts of climate change on coastal populations, describing the concepts put forward in different IPCC
149 reports. Section 3 is an analysis of methods and results from a selection of the most cited global
150 vulnerability assessments on marine and coastal systems in order to highlight limitation of vulnerability
151 assessments conducted at the global scale. Section 4 proposes a two-tier approach as a way forward to
152 provide guidance for future vulnerability assessments on coastal and marine issues.
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161 **2. Contrasted conceptualizations of vulnerability and associated concepts**

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171 Vulnerability is a concept that is intuitively understandable and simple because it is used in many
172 everyday life contexts: one can be vulnerable to diseases, attacks etc. This concept allows for integration
173 of physical, ecological, and human impacts of and adaptability to climate change. The concept emerged
174 in its current form in relation to environmental studies in the 1980s (Timmerman, 1981), disaster risk
175 reduction at the local level in the 1990s (e.g. Weichselgartner, 2001), political ecology and resilience in
176 the 2000s (Eakin & Luers, 2006) and has evolved over time to be used by interdisciplinary research on a
177 number of topics including climate change (Turner et al., 2003). During this evolution, climate change
178 vulnerability assessments have become more complex, building from impact assessments to include
179 non-climate drivers (of environmental or socio-economic nature) and adaptation responses (Füssel &
180 Klein, 2006). However, there is no consistent definition nor conceptualization of vulnerability yet (Adger,
181 2006). Vulnerability research efforts are currently focusing on developing independent vulnerability
182 approaches and indexes to test their relevance and applicability for adaptation planning. The
183 vulnerability concept lacks an operational definition and measurement for consistent practical
184 applications (Adger, 2006), because it is difficult to choose among competing approaches or to
185 understand their differences (O'Brien et al., 2007). Ten years later there is not much evidence of
186 significant improvement in this area, which has led to tensions in international climate negotiations
187 (Oculi & Stephenson, 2018).

192 The evolving nature of the definition and analytical framework used for assessing vulnerability can be
193 best illustrated through the evolution of the framework used by the IPCC between 2001 and 2014 (Figure
194 1. a,b). In the IPCC Third Assessment Report of 2001, vulnerability was defined as “a function of the
195 character, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its
196 adaptive capacity” (Schneider and Sarukhan, 2001, p.92, Figure 1.a). In the Fifth Assessment Report -and
197 already in the IPCC Special Report on EXtreme events and disasters (IPCC, 2012), the definition of
198 vulnerability was revised to best capture systems complexity: “the propensity or predisposition to be
199 adversely affected. Vulnerability encompasses a variety of concepts and elements including sensitivity or
200 susceptibility to harm and lack of capacity to cope and adapt” (Oppenheimer et al., 2014, p.1046, Figure
201 1.b). This evolution of thinking was not followed by guidelines to operationalize this new conceptual
202 framework, so it is left to different disciplines to assess and integrate the complex facets of vulnerability
203 as they are described by the IPCC. To add to the challenge, the vulnerability framework is applied to a
204 variety of perspectives in the IPCC reports (vulnerability of ecosystems, populations, the economy),
205 adding confusion over the message conveyed.

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211 *Figure 1 here.*

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215 Even though conceptualizations differ for the definition of vulnerability, the core of the vulnerability
216 framework remains relatively unchanged and can be boiled down to its components of hazard, exposure,
217 sensitivity, adaptive capacity and vulnerability (Figure 2.). Key differences between the frameworks lie in
218 the way the relationship between vulnerability and the other factors is formalized, and the feedbacks
219 and actions that influence and are influenced by vulnerability - namely adaptation, mitigation, and
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227 governance. This flexibility in the framework makes the vulnerability concept well suited to analysis at
228 the local level, where more context specific information is available (Hinkel, 2011). It makes however the
229 concept more difficult to use at the global level in a consistent way, which would require more of a
230 'blueprint' approach if it is to guide investments across different types of risks and social contexts with
231 some degree of equality and comparability.
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236 *Figure 2 here.*
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242 **3. What do global vulnerability assessments actually reveal: understanding** 243 **conflicting vulnerability rankings from climate change impacts on coastal** 244 **human populations** 245 246 247

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249 A number of global indicator assessments, applied to marine resources, have been conducted by
250 academics (Allison et al., 2009; Barange et al., 2014; Blasiak et al., 2017; Cooley et al., 2012; Halpern et
251 al., 2012; Hughes et al., 2012; Monnereau et al., 2017) and Non-Governmental Organizations (Beck,
252 2014; Burke, Reynter, Spalding, & Perry, 2011; Harrould-Kolieb, Hirshfield, & Brosius, 2009; Huelsenbeck &
253 Vorpahl, 2012) to assess ocean health and the specific risks faced by marine ecosystems and the people
254 that depend upon them. Eight of these 11 global vulnerability assessments are compared here. Three
255 papers are not taken into account because of specific focus on mollusks (Cooley et al., 2012) or because
256 they base their analysis on a paper already reviewed here (Monnereau et al. 2017; Blasiak et al., 2017).
257 The selection of the international literature reviewed here includes seminal papers focusing on coastal
258 and marine vulnerability at the global scale, totalizing 2509 citations according to Google Scholar, and is
259 not intended as a systematic review of the scientific effort on vulnerability assessments. The analysis of
260 this literature focuses on the methods and results published by global vulnerability assessments in order
261 to highlight limitations for applications at the global scale.
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265 Each has appropriated and redefined the core concepts of the approach differently (Table 1). All of these
266 studies have the aim to measure the vulnerability of societies to changes in the ocean, whether it is
267 fisheries, coral reefs, or a range of ecosystem services provided by the ocean. Most assessments define
268 vulnerability as a combination of exposure, sensitivity, and adaptive capacity and measure it using
269 indicators that fit in these three categories. The formulae used to calculate vulnerability itself vary across
270 these studies. Four of the studies calculate vulnerability as a function of exposure, sensitivity, and
271 adaptive capacity. Two studies only measure exposure and sensitivity. The ocean health index measures
272 different but related concepts, including current state, trends, pressures, and resilience. Since the
273 introduction of a new definition of vulnerability by the IPCC in 2012, one report (Beck, 2014) uses this
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283 new definition, where risk is a function of exposure and vulnerability, and vulnerability is a function of
284 sensitivity and adaptive capacity.
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288 *Table 1 here.*
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292 Even when definitions are common, the indicators and corresponding datasets used to measure hazard,
293 exposure, sensitivity, adaptive capacity, mostly in relation to available data and specific focus of these
294 studies. A recent analysis of ten global climate vulnerability assessments (6 of which are also analysed
295 here, the other four being general vulnerability assessments not targeted at coastal and marine systems)
296 found important methodological differences across studies: a difference in the number of countries
297 taken into account, the use of socio-economic indicators not scaled to population size, the small number
298 of indicators used and the lack of redundancy test for the selected indicators (Monnereau et al., 2017).
299 While using similar basic frameworks, the existing global-level studies of the climate impacts to coastal
300 populations use different indicators composed of multiple variables to determine exposure, sensitivity
301 and adaptive capacity. For instance, these studies differ in terms of the hazards they take into account,
302 exposed populations, dependence of livelihood and infrastructure, and capacity to deal with climate
303 change. Starting from the same framework developed by Allison et al. (2009) to study the vulnerability of
304 marine fisheries, two groups of researchers introduced different methodological improvements and
305 choice of indicators that have led to the conclusion that LDCs are more vulnerable in the first case
306 (Blasiak et al., 2017) whilst SIDS are more vulnerable in the other (Monnereau et al., 2017).
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313 As a result of different definitions, conceptual representations, and indicators used in global assessments
314 of coastal and marine risks, very different rankings of priorities for countries at risk have been
315 established. Table 2 shows a large number of different countries that appear in the 'top 10' most
316 vulnerable for the eight global assessments. Of these, 53% of countries (or 42 out of 79) appear in the
317 top 10 of only one of the reports, suggesting more difference than coherence. No country is found in the
318 top 10 of all of the reports and only two countries, Sierra Leone and the Philippines, are found in the top
319 10 of half the reports. This finding corroborates a previous comparison of national level studies that
320 found great differences in indicators and countries ranking (Eriksen & Kelly, 2007).
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331 *Table 2 here.*
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341 The lack of consistent operational definition and measurement of vulnerability means it is difficult to
342 discriminate between existing vulnerability approaches and identify the “right one” from a theoretical
343 perspective. In an effort to be more comprehensive and to reflect the different abilities of coastal
344 populations to deal with climate change, recent indicator-based global level assessments include coping
345 and adaptive capacities. Multiple factors influence the capacity of coastal populations to respond to
346 climate change, depending on the local socio-economic characteristics, multi-level governance, but also
347 cultural norms and customs, and perceptions of risk (Cinner et al., 2018; Evans et al., 2016). Adaptive
348 capacity is often the most complex component of vulnerability to understand, define, and collect data on
349 because it is the most context-specific. Some empirical work suggests that global adaptive capacity
350 indicators can be identified (Brooks, Adger, & Kelly, 2005) but they so far reflect generic issues such as
351 education and poverty that may be very important for development and well-being but not necessarily
352 for dealing with sectoral impacts of climate change (Hughes et al., 2012). All but two of these studies
353 include measures of capacity (Barange et al., 2014; Harrould-Kolieb et al., 2009).

357 Metrics of adaptive capacity used in the eight global vulnerability assessments were categorized into the
358 five domains of adaptive capacity described in (Cinner et al., 2018). “Assets” include resources of
359 different nature (economic, technological, environmental), “Flexibility” measures the diversity of
360 possible options to adapt to climate change, “Organizations” describes governance and social cohesion,
361 “Learning” captures the generation and utilization of knowledge, and “Agency” describes the ability of
362 people and organizations to mobilize the other domains of adaptive capacity into action. Some
363 assessments already use a similar way of categorizing their adaptive capacity metrics (Hughes et al.,
364 2012). Others use different labels. For example in the Ocean Health Index, these metrics are found under
365 the term social resilience. In other reports (Allison et al., 2009; Coasts at Risk; Reefs at Risk), categories
366 include economy, health, education, and governance. When adaptive capacity categories are different
367 from (Cinner et al., 2018), we use in-text justification of the choice of metrics to categorize them.

371 Similarities and differences can be found in the metrics used for measuring adaptive capacity in these
372 assessments (Table 3). Assets and organization contain the most number of metrics. Agency metrics are
373 the least commonly found across studies and is not consistently measured. Agency is a difficult concept
374 to operationalize with quantitative measures. Measuring the empowerment and freedom of people and
375 institutions to adapt and shape their livelihoods is a frontier of researcher, with few papers investigating
376 barriers to adaptation (Barnett et al., 2015; Weichselgartner & Kasperson, 2010). Metrics of assets and
377 learning are consistent across the studies, with GDP per capita, life expectancy, and adult literacy rate
378 being the most used metrics. In fact, these are the metrics found in the widely used Human
379 Development Index (Sen, 1994), which raises issues of redundancy and more importantly relates to
380 development policies and ideologies (McGillivray, 1991). Metrics of natural assets are also not consistent
381 across studies. Organization is defined consistently, with global metrics available to characterize this
382 concept, including the fisheries management effectiveness index developed by (Mora et al., 2009).
383 However, different studies include a wide variety of other metrics besides fisheries management
384 effectiveness to characterize organization. Flexibility metrics are all related to access to alternative
385 sources of livelihood, but are measured inconsistently across studies.

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397 *Table 3 here.*
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401 There are two immediate consequences of the use of adaptive capacity measures in these assessments.
402 First, developed countries that face large potential impacts from climate change do not rank high – even
403 though the value of needed adaptation related investment may be extremely large. Second, it becomes
404 difficult to know, using final scores alone, whether a country with a high indicator score is due to
405 vulnerability caused by climate change or inherent vulnerabilities caused by demographic, political, and
406 social factors. The recent developments in vulnerability assessments attempt to include more targeted
407 measures of adaptive capacity that are not yet rooted in empirical evidence. Causal relationships
408 between adaptive capacity and impacts in social-ecological systems are still lacking (Breshears, López-
409 Hoffman, & Graumlich, 2010; Scheuer, Haase, & Meyer, 2011).
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412 A lack of an agreed definition, a lack of standard measurements of vulnerability across studies and an
413 ambiguous use of the concept for multiple perspectives (what/who is vulnerable to what changes) have
414 partly impaired the establishment of clear unambiguous global assessments. It is therefore of little
415 surprise that such global assessments have, in turn, not been able to help set up clear priorities for
416 climate investment and action.
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421 **4. A two-tiered approach for global assessment to inform climate investment** 422 **and action** 423

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425 To avoid the challenges described in section 2 and section 3 and to move towards a more transparent
426 approach to global indicator assessments that can be used to identify climate action, a simplification and
427 harmonization of assessments is needed. The goal of global level assessments should remain to
428 understand the impacts of climate change at the global level for coastal human populations, but the
429 methodology to do so must evolve. Specifically, a two-tiered approach is suggested for classifying
430 existing studies to better identify common elements, and guide further global analysis (Figure 3.):
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433 1. GLOBAL LEVEL IMPACT ASSESSMENTS (first tier): Global level assessments should focus on simplified
434 and more standardized scoping studies for which good global data are available. These simpler
435 approaches should link climate change directly to impact, be limited to impacts, and not include
436 measures of adaptive capacity so as to clearly separate development issues from threats driven by
437 climate change. A focus on global-level impact assessments can help identify countries where:
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439 a. climate action may be warranted (mitigation, adaptation or other),

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441 b. additional, finer scaled vulnerability assessments may provide crucial information to set up
442 appropriate policy action, and
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451 c. monitoring and science may yield socially relevant results.
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453 The scores used to rank countries could be presented by impact or as a summary measure of how high-
454 ranked countries scored across the impacts considered. The impacts of climate change are direct
455 pathways through which the effects of climate change will adversely affect species, ecosystems, and
456 socio-economic systems. Climate effects include ocean warming, acidification, sea-level rise, changes in
457 extreme weather events, deoxygenation, modification of currents, and changes in salinity (Hoegh-
458 Guldberg et al., 2014). Examples of such studies include impacts of climate effects on economic sectors
459 in general (Allison & Bassett, 2015; Weatherdon et al., 2016), on fisheries (Barange et al., 2014; Cheung
460 et al., 2009, 2010), on ecosystem services (Pendleton et al., 2016), or on global ecosystems (Hoegh-
461 Guldberg & Bruno, 2010). Global-level scoping analyses based on impacts are meant to guide more
462 refined and more data-intensive local level analyses, but do not aim to replace such local level analyses.
463 Ideally, such analyses are accompanied by a global scale analysis of technical, economic and social costs
464 of action for comparison to potential benefits from impact mitigation and adaptation. They should also
465 be accompanied by analysis of the equity and justice repercussions of the distribution of potential
466 impacts (Wolff et al., 2015), which was partly the role of including adaptive capacity in vulnerability
467 assessments.
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472 2. LOCAL LEVEL ASSESSMENTS (second tier): The global scoping assessments should identify places
473 where more comprehensive local level assessments can be conducted to identify concrete investment
474 actions and the degree to which these places are vulnerable to climate change, including the socio-
475 economic and political factors influencing vulnerability.
476

477 At the local level, more refined, data-intensive analysis can be used to better understand local impacts of
478 global and local changes and behaviors. Such analyses would include, but not be limited to, vulnerability
479 assessments, and would help identify key environmental and ecological factors affecting human
480 dependencies which are most impacted by climate change. At this level, the socio-economic and political
481 factors influencing adaptive capacity can be identified and assessed in a vulnerability framework. There
482 already exists a number of relevant local level assessments which have been successfully applied in
483 developed and developing countries that could be better used to understand climate impacts and
484 actions (e.g. Cinner et al. 2012; Ekstrom et al. 2015; Gupta et al. 2010).
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489 *Figure 3 here.*
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493 This two-tiered approach is a pragmatic way to make the most of available data, approaches and
494 scientific methods to undertake meaningful assessments that can guide climate action and help prioritize
495 efforts where most urgently needed. It also helps provide a global-level, transparent framework while
496 keeping local flexibility for climate investment and action from the global down to the local level. Like
497 vulnerability assessments, the approach combines natural and social sciences to understand the
498 potential impacts on people of climate change, but it does so at levels that better match the social
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507 science concepts to the scale at which relevant data are available. The first tier allows for meaningful
508 policy recommendations at the global level, while the second tier provides the needed flexibility in
509 relation to changing spatial and human contexts.
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512 Such a two-tiered approach still requires continued improvements in the quality and quantity of natural
513 and social science data. While natural science data regarding climate, oceanography, corals and fisheries
514 continues to improve, social human data lag behind, especially data about local fisheries, tourism and
515 the built environment as well as preparedness, capacity to act and representations. There is a need for
516 better data and science to be able to structure global-level assessments in a globally coherent and
517 meaningful way, with a need for research and data collection efforts to be targeted accordingly.
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519
520 The semantics used in the international policy arena are framed around the term “vulnerability” and are
521 making it difficult to move past vulnerability assessments at the global scale. While assessing potential
522 impacts instead of vulnerability at the global scale is important, targeting vulnerable countries is a policy
523 agenda that may be hard to challenge (Klein, 2009). This even though current international funds are not
524 necessarily targeting “vulnerable countries” which do not have the capacity to apply for funding (Tango
525 International & ODI, 2015).
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527
528 The suggested way forward corresponds to taking a step back and adopts a simplified approach. Instead
529 of trying to derive meaningful guidance from applying one tool at inappropriate scales of analysis
530 (vulnerability assessments applied at the global level), a combination of scale-relevant tools could be
531 applied. This would amount to shifting the emphasis from using tools at the global level to identify local
532 impacts (i.e. the downscaling of global results to the local level) to using tools at the global level to
533 identify potential local impacts and inform local analysis and appropriate action. It seems that this
534 interfacing of a top-down approach and a bottom-up approach is gaining momentum in the design of
535 new vulnerability assessments (Hobday et al., 2016; Mastrandrea, Heller, Root, & Schneider, 2010; Wilby
536 & Dessai, 2010).
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541 **5. Conclusion**

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544 Current global vulnerability assessments are not able to fulfil their goal to give clear guidance towards
545 the identification of vulnerable countries. Shortcomings include a lack of agreed definitions, concepts,
546 and metrics to measure vulnerability. Adaptive capacity is particularly problematic to assess at the global
547 scale. If they are to be useful to decision-makers with a global reach, including Inter-governmental
548 Organizations, Multi-lateral funds such as the Green Climate Fund and global NGOs, global level
549 assessments should not be designed and applied as comprehensive studies but rather as scoping studies
550 that focus clearly on the basic pathways that link climate change to impacts on people, without
551 extending the analysis to determine overall vulnerability which is context specific. These global level
552 “impact assessments” then should be supplemented by more refined local level vulnerability
553 assessments and analyses of costs of action to provide information useful to climate action and
554 investment from the global down to the local level.
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563 The first tier of the two-tiered approach could be useful to identify all countries that are likely to
564 experience large direct or indirect impacts from climate change. If applied to a pool of recipient
565 countries alone (*i.e.* developing countries under Article 4.4 of the UNFCCC receiving international
566 transfers), such a tier could be used to identify places where foreign assistance to meeting the costs of
567 adaptation under the UNFCCC may be most useful and improve efficiency of international climate
568 funding. The second tier could be used by developed and developing countries alike to inform more fine-
569 tuned context-appropriate investment within countries, and not just international transfers. This second
570 tier can consider different types of action, including climate change action but not exclusively, and
571 different investment options into mitigation, adaptation, governance and science. It can broaden
572 stakeholder engagement at the local level to include civil society and other parties that could improve
573 country ownership and improve effectiveness of climate action (Brown, Polycarp, & Spearman, 2013;
574 Lebel et al., 2006). Global mechanisms need to use objective criteria to prioritize investments and actions
575 and vulnerability assessments will remain an important tool to do so.
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579 In addition to the two tiers proposed here, parallel but separate analyses of costs of action including
580 technical, social and economic factors should be conducted at multiple scales. There are enormous gaps
581 in terms of finance, technology, and knowledge for adaptation -particularly in developing countries-
582 (UNEP, 2014), but a detailed estimate of investment needs for coastal populations is lacking.
583 Vulnerability and impact assessments are not sufficient to identify and appraise actions to respond to
584 climate change (Tulloch et al., 2015). The combination of the two-tiered approach and analyses of costs
585 of action should provide necessary information for informed climate investment and action.
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589 590 **ACKNOWLEDGMENTS**

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592 This manuscript was developed after an earlier note published in OCEAN AND CLIMATE, 2015 – Scientific
593 Notes. www.ocean-climate.org, 116 pages. This research was possible thanks to a grant from the Prince
594 Albert II of Monaco Foundation and a grant from the Region of Brittany. It was also supported by the
595 "Laboratoire d'Excellence" LabexMER (ANR-10-LABX-19) and co-funded by a grant from the French
596 government under the program "Investissements d'Avenir". This research was also supported by the
597 French National Initiative for Coral Reefs (IFRECOR) program. We are thankful to J. Ekstrom for providing
598 helpful comments.
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603 604 **REFERENCES**

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Figure 1. Conceptual frameworks of vulnerability used by the IPCC in (a) the Third assessment report of 2001 and (b) the Fifth assessment report of 2014. Sources: (a) “Places of adaptation in the climate change issue” (Schneider and Sarukhan, 2001, p.90) (b) “Schematic of the interaction among the physical climate system, exposure, and vulnerability producing risk” (Oppenheimer et al., 2014, p.1046).

Figure 2. Contributing factors to potential impacts and vulnerability (adapted from Ionescu et al., 2009; Schneider and Sarukhan, 2001). Exposure, sensitivity and hazard event (bold) are predictive and speculative outcomes that lead to potential impacts. Vulnerability is the combination of potential impacts and adaptive capacity. * Adaptive capacity is highly context specific.

Figure 3. 2-tier strategy to conduct assessments vulnerability assessments at different scales.

Table 1. Objectives, definitions of vulnerability, and formulae used in eight global reports. (V) vulnerability, (E) exposure, (S) Sensitivity or dependence, (CC) coping capacity, (AC) adaptive capacity, (OHI) Ocean Health Index, (C) current status, (T) trend, (P) pressure, (Re) resilience

	Harrould-Kolieb et al., 2009	Allison et al., 2009	Burke et al., 2011	Huelsenbeck & Vorpahl, 2012	Hughes et al., 2012	Beck, 2014	Barange et al., 2014	Halpern et al., 2012
Objectives	"evaluated the likely vulnerability of different countries to continued ocean acidification" p.1	"we provide an indicator-based analysis of the relative vulnerabilities of 132 countries to climate change impacts on fisheries." p.175	"developed a new, detailed assessment of the status of and threats to the world's coral reefs. This information is intended to raise awareness about the location and severity of threats to coral reefs. These results can also catalyze opportunities for changes in policy and practice that could safeguard coral reefs and the benefits they provide to people for future generations." p.1	"ranks nations based on the seafood security hardships they may experience by the middle of this century due to changing ocean conditions from climate change and ocean acidification." p.2	"develop a framework to identify most vulnerable regions, the mechanisms creating this vulnerability, and the potential policy interventions that may this reduce food security vulnerability." p.96	"1) examines the risks that nations face from vulnerability and exposure to coastal hazards; 2) identifies where environmental degradation contributes to these risks; and 3) explores where environmental solutions can contribute to risk reduction." p.2	"develop and link models of physical, biological and human responses to climate change in 67 marine national exclusive economic zones, which yield approximately 60% of global fish catches, to project climate change yield impacts in countries with different dependencies on marine fisheries" p.211	"developed and implemented a systematic approach for measuring overall condition of marine ecosystems that treats nature and people as integrated parts of a healthy system." p.1
Definition of vulnerability	"based on the magnitude of their fish and shellfish catch, their level of seafood consumption, the percentage of coral reefs within their exclusive economic zones (EEZ) and the projected level of ocean acidification in their coastal waters in 2050." p.1	"a combination of the extrinsic exposure of groups or individuals or ecological systems to a hazard, such as climate change, their intrinsic sensitivity to the hazard, and their lack of capacity to modify exposure to, absorb, and recover from losses stemming from the hazard, and to exploit new opportunities that arise in the process of adaptation" p.175	"We represent vulnerability as the combination of three components: exposure to reef threats, dependence on reef ecosystem services (that is, social and economic sensitivity to reef loss), and the capacity to adapt to the potential impacts of reef loss." p.66	"combining each nation's exposure to climate change and ocean acidification, its dependence on and consumption of fish and seafood and its level of adaptive capacity based on several socioeconomic factors." p.2	"degree to which a country is susceptible to a decline in coral reef fisheries as a food source and is ability to respond to the decline." p.96	"Risk is a function of exposure of people and assets to a geophysical hazard (e.g., flood) and the social vulnerability of communities. The three components of vulnerability are susceptibility, coping capacity and adaptive capacity." p.2	"depends on three key elements: exposure to the physical effects of climate change; economic and social dependency on the changing variable(s); and adaptive capacity to the changes." p.214	N/A
Formulae for vulnerability	$V=E+S$	$V=f(E, S, AC)$	$V=E*S*AC$	$V=E+S-AC$	$V=E+S-AC$	$V=S+CC+AC$; Risk= $E*V$	$I=E*S$	OHI = $f(C, T, P, Re)$

Table 2. Top 10 countries at risk from climate change impacts on the coasts and ocean, extracted from eight global reports and listed regardless of their original rank. In red, countries found in four of the reports, in orange, countries found in three of the reports, in yellow, countries found in two reports, in white countries found in only one of the reports. *Burke et al. (2011) only identifies 9 countries as highly vulnerable

Vulnerability Ranking								
	Burke et al., 2011*	Hughes et al., 2012	Barange et al., 2014	Halpern et al., 2012	Huelsenseck & Vorpahl, 2012	Beck, 2014	Allison et al., 2009	Harrould-Kolieb et al., 2009
Top 10 countries	Philippines	Philippines	Sierra Leone	Sierra Leone	Sierra Leone	Philippines	Sierra Leone	Philippines
	Kiribati	Indonesia	Ivory Coast	Ivory Coast	Kiribati	Kiribati	DR Congo	Indonesia
	Indonesia	Liberia	Liberia	Liberia	Comoros	Fiji	Mozambique	Australia
	Comoros	Ivory Coast	Senegal	DR Congo	Mozambique	Vanuatu	Senegal	France
	Fiji	Tanzania	Togo	Haiti	Togo	Antigua & Barbuda	Angola	Japan
	Haiti	Cambodia	Benin	Dominica	Cook Islands	Bangladesh	Mali	Malaysia
	Vanuatu	Cameroon	Gambia	East Timor	Eritrea	Brunei Darussalam	Mauritania	Netherlands
	Grenada	Egypt	Ghana	Libya	Madagascar	Saint Kitts & Nevis	Niger	New Zealand
	Tanzania	Honduras	Guinea-Bissau	Nicaragua	Pakistan	Seychelles	Peru	United Kingdom
		Kenya	Iceland	St. Vincent & Grenadines	Thailand	Tonga	Russian Federation	United States

Table 3. Adaptive capacity metrics extracted from eight global vulnerability assessments reports and categorized according to the five domains described in (Cinner et al., 2018). Compared to Tables 1&2, Barange et al. (2014) and Harrould-Kolieb et al. (2009) do not use adaptive capacity metrics in their vulnerability index and therefore are not presented here

Categories	Burke et al., 2011	Hughes et al., 2012	Halpern et al., 2012	Huelsensbeck & Vorpahl, 2012	Beck, 2014	Allison et al., 2009
Assets	GDP + remittances per capita	GDP per capita	Global Competitiveness Index	GDP per capita	Public health expenditure	Total GDP
	Average life expectancy	% of population with access to sanitation	Access to artisanal fishing	% of the population undernourished	Life expectancy at birth	Healthy life expectancy
		Reef area per capita	Ecological integrity	Population growth rate 2012-2050	Private health expenditure	
					# physicians and # hospital beds per 10000 inhabitants	
					Water resources	
					Fish stock status	
Flexibility	% of population within 25km of market centers	Trade balance standardized by GDP per capita	Sector diversity		Livelihood diversity index	
	Agricultural land area per agricultural worker	GINI index			Insurances	
Organization	Fisheries subsidies that encourage resource conservation and management, as a % of fisheries value	Fisheries management effectiveness	Fisheries management effectiveness		Fisheries management effectiveness	Political stability
	Worldwide Governance indicator	Government effectiveness index	Worldwide Governance indicator		Corruption perception index	Government effectiveness
		Score indicating mention of fisheries management in national-level policy documents	Marine Protected areas		Failed states index	Regulatory quality
			Management effectiveness of artisanal fishing		Agricultural management	Rule of law
			Mariculture sustainability Index		Biodiversity and habitat protection	Corruption
					Forest management	
Learning	Adult literacy rate	Adult literacy rate			Adult literacy rate	Adult literacy rate
	Combined ratio of enrollment in primary, secondary, and tertiary education	Scientific robustness			Gender parity in education	School enrolment % in primary, secondary and tertiary education
					Combined gross school	

					enrollment	
Agency			CBD survey and signatories		% female representative in Parliament	Voice and accountability
			CITES signatories			

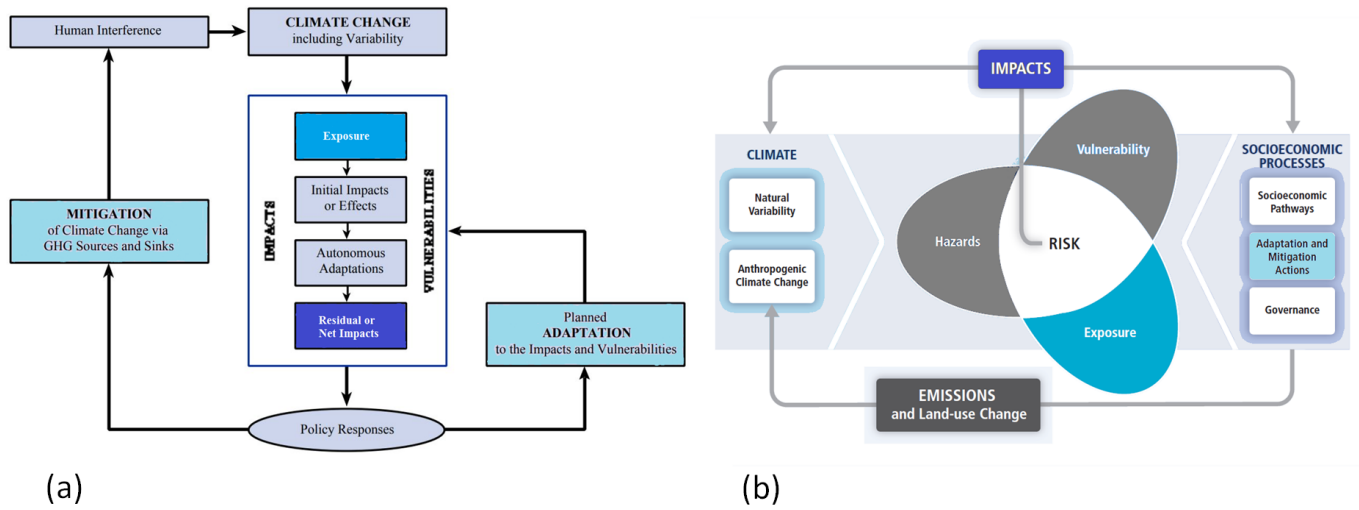


Figure 1. Conceptual frameworks of vulnerability used by the IPCC in (a) the Third assessment report of 2001 and (b) the Fifth assessment report of 2014. Sources: (a) “Places of adaptation in the climate change issue” (Schneider and Sarukhan, 2001, p.90) (b) “Schematic of the interaction among the physical climate system, exposure, and vulnerability producing risk” (Oppenheimer et al., 2014, p.1046).

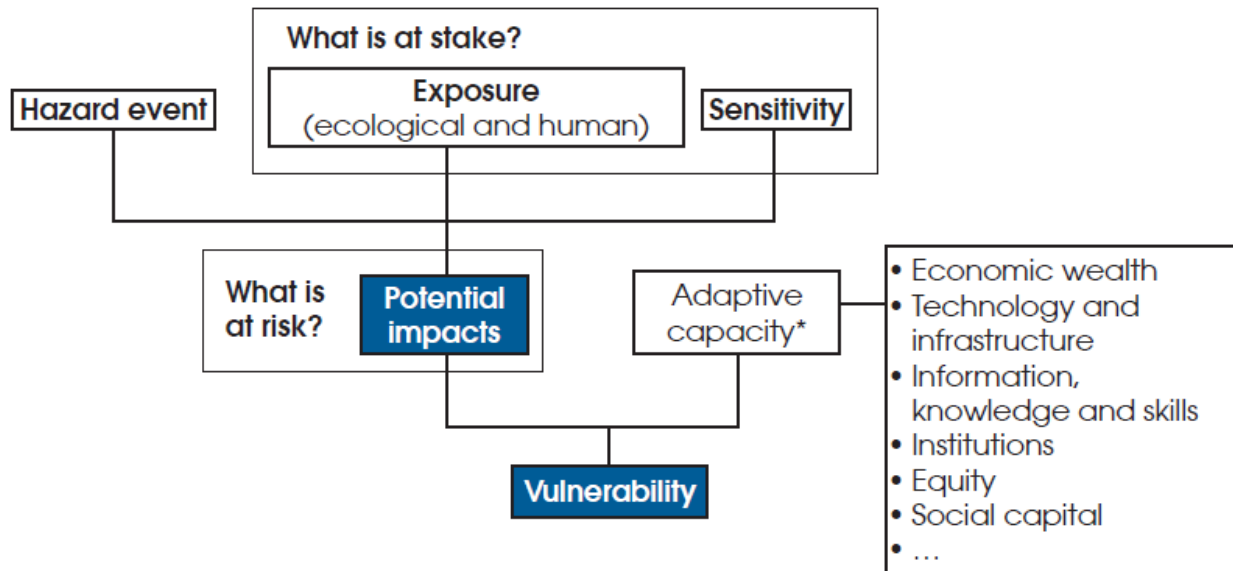


Figure 2. Contributing factors to potential impacts and vulnerability (adapted from Ionescu et al., 2009; Schneider and Sarukhan, 2001). Exposure, sensitivity and hazard event (bold) are predictive and speculative outcomes that lead to potential impacts. Vulnerability is the combination of potential impacts and adaptive capacity. *Adaptive capacity is highly context specific.

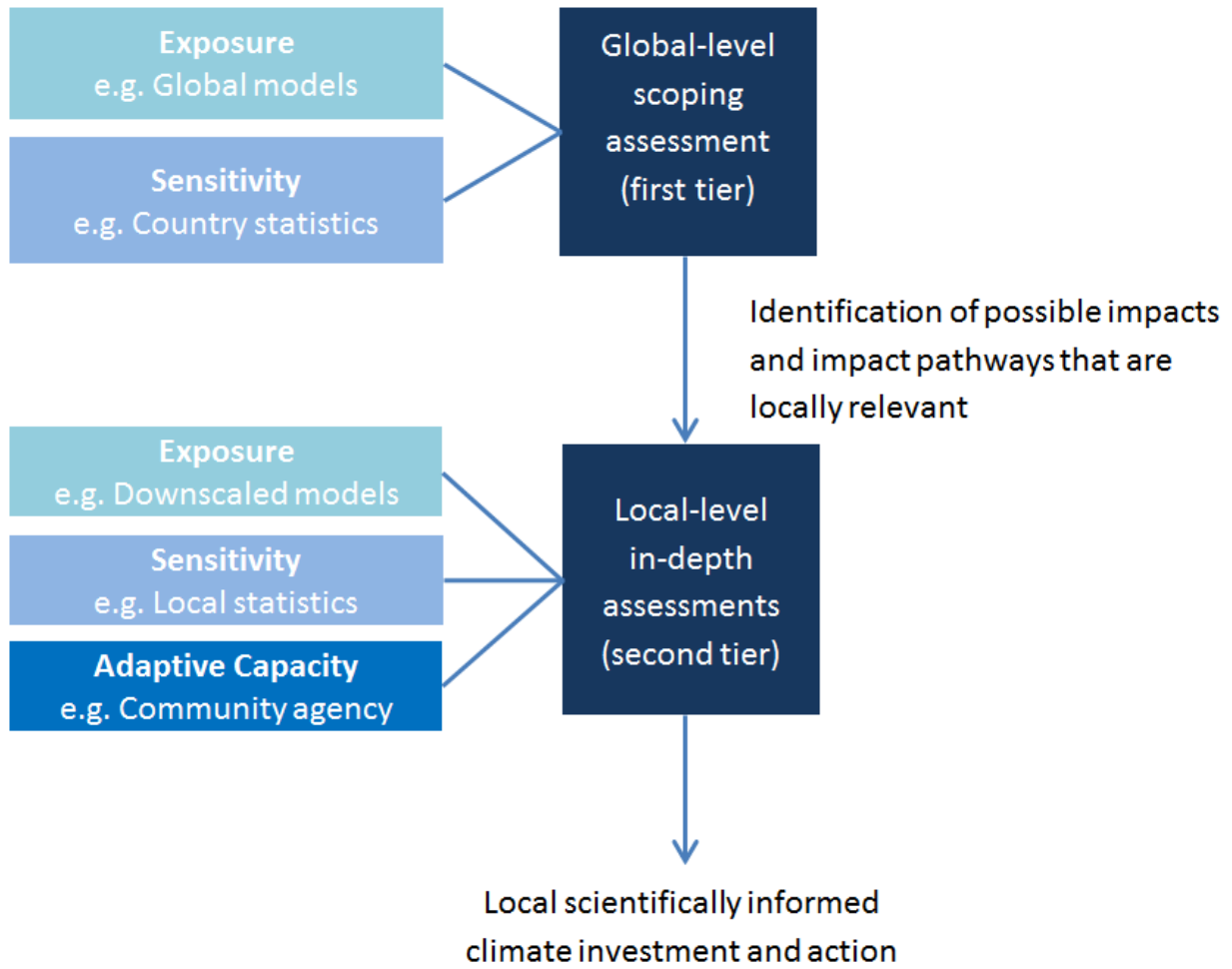


Figure 3. 2-tier strategy to conduct assessments vulnerability assessments at different scales.