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Scenarios for vulnerability: opportunities and constraints in the context of climate change and disaster risk

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Abstract Most scientific assessments for climate change adaptation and risk reduction are based on scenarios for climatic change. Scenarios for socio-economic development, particularly in terms of vulnerability and adaptive capacity, are largely lacking. This paper focuses on the utility of socio-economic scenarios for vulnerability, risk and adaptation research. The paper introduces the goals and functions of scenarios in general and reflects on the current global debate around shared socio-economic pathways (SSPs). It examines the options and constraints of scenario methods for risk and vulnerability assessments in the context of climate change and natural hazards. Two case studies are used to contrast the opportunities and current constraints in scenario methods at different scales: the global WorldRiskIndex, based on quantitative data and indicators; and a local participatory scenario development process in Jakarta, showing a qualitative approach. The juxtaposition of a quantitative

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approach with global data and a qualitative-participatory local approach provides new insights on how different methods and scenario techniques can be applied in vulnerability and risk research.

1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) Special Report on Managing the Risk of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) underscores the need for improved consideration of the dynamic nature of vulnerability and its changes over time and in space. The report emphasises that developing estimates about future vulnerability and response capacities is at least as challenging as estimating the likelihood of physical events and so-called extreme events (IPCC 2012, p. 46). The report also expresses the need for improved methods to predict and estimate future vulnerability, but provides few examples on how to conduct such assessments. It becomes critically important to explore whether and how scenario methods (e.g. quantitative and qualitative) can be used in vulnerability research, especially since risk reduction and adaptation needs are dependent on both future climatic conditions as well as future societal conditions.

This paper examines the application of scenario methods in vulnerability research. It addresses the following key questions:

- How can scenario methods be applied to vulnerability assessments at different scales to improve the capacity to estimate potential future vulnerability patterns?
- What are the specific opportunities and constraints of quantitative and more qualitative scenario methods for vulnerability and risk assessments?

The key contribution of this paper is to test the applicability of two different scenario methods (top-down and bottom-up) for vulnerability and risk research. The first method is a quantitative vulnerability and risk-assessment approach based on the global WorldRiskIndex concept. The second is a qualitative local-scenario approach (bottom-up) based on a local participatory process developed for Jakarta by a team of risk and adaptation researchers, integrated assessment modellers and urban development experts.

The paper bridges the disaster risk and climate change communities. Scenario methods have not been used much in disaster risk research. The climate change community, on the other hand,

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is heavily engaged in scenario work, especially on aspects related to mitigation (e.g. Special Report on Emission Scenarios [SRES] scenarios) or on the assessment of impacts (see e.g. IPCC 1994). For example, scenarios have been used to examine the influence of development and climate change on the incidence of future infectious disease mortality (Tol et al. 2007). Using proxy indicators (infant mortality, for example where data are more readily available) to project future disease mortality, the scenarios suggest that changes in development indicators (poverty, literacy) influence infant mortality rates, which in turn lead to proportional changes in the potential malaria death toll, because the two are closely related. However, broader concepts of human vulnerability and risk are rarely included in such scenarios.

The paper begins with an introduction into scenario methods. This is followed by the introduction of a new scenario framework for integrated adaptation and mitigation research and the presentation of the two case studies. The final section presents key conclusions and an outlook for the utilisation of scenarios for assessing future vulnerability patterns.

2 Functions and goals of scenarios

Various methods have been developed to create scenarios ranging from simplistic to complex models, qualitative to quantitative methodologies, as well as expert versus non-expert oriented approaches (Glenn et al. 2009; Gordon 2009). In the area of climate change adaptation and disaster risk reduction, most scenarios have been developed in the domain of natural hazards or physical changes to the climate system (climate change scenarios, emissions scenarios [see SRES] etc.), with less work done on scenarios for vulnerability (e.g. IPCC 1994; Giannini et al. 2011; Jones and Preston 2011).

A scenario characterises a hypothetical state of a system in the future (Scholz and Tietje 2002). Scenarios represent a mechanism for describing future trends and/or conditions for a specific point in time, despite the unknown degree of irreducible uncertainty about the future (Kok et al. 2011). Scenarios allow us to illustrate and discuss potential directions and evolutionary paths that development processes might take, drawing attention to the potential consequences for decision-making and management strategies (Glenn et al. 2009; van Vuuren et al. 2012a). Generally speaking, scenarios:

- make the future(s) more realistic and understandable for decision makers and force new thinking;
- help understand the significance of uncertainties;
- illustrate different potential development pathways, underscoring possible and undesirable or desirable development directions;
- help to identify policies and measures that are appropriate and beneficial in specific scenarios and, hopefully, across a range of possible scenarios (Glenn et al. 2009; Preston et al. 2009; Hallegatte et al. 2011; van Vuuren et al. 2012a, b).

Scenarios often fulfil at least two key functions. First, they have *analytic* and *explorative functions* in that they facilitate a systematic discussion of current conditions and potential future development trends. Second, scenario development also has a *normative function* in that it allows for a discussion of desirable or undesirable development patterns and futures. Different scenarios can be compared and more desirable and non-desirable futures can be discussed. Participatory scenario methods also can help identify underlying normative assumptions about development trends and their role within specific framings, e.g. the context of climate change adaptation. Scenario development in participatory or transdisciplinary processes can strengthen trust-building and mutual learning (Wiek et al. 2006). In this regard assessments and scenario approaches can be differentiated according to two primary perspectives: top-down versus bottom-up (see Jones and Preston 2011).

Today there is a variety of approaches to constructing scenarios. However, most are based on the following criteria: a) they should be plausible, describing a rational route from "here" to "there" that makes causal processes and decisions explicit; b) they should be internally consistent; and c) they should be sufficiently interesting and exciting to make the future "real" enough to elicit strategic responses (see Glenn et al. 2009; Gordon 2009; Hallegatte et al. 2011).

3 The new scenario framework for adaptation and mitigation

The climate change research community is presently engaged in the development of a new framework for creating and using scenarios to improve the assessment of climate change, its impacts, and response options (Moss et al. 2010), called the Shared Socio-economic development Pathways (SSPs) (Kriegler et al. 2012; van Vuuren et al. 2012b; O'Neill et al. 2013). One of the key aims of the SSP architecture is to facilitate research and assessment modelling that can inform policymakers about the challenges in *mitigation* efforts as well as provide information about potential ranges of *adaptation* efforts. Compared to the former SRES scenarios, the SSPs address the challenges for adaptation. In so doing they provide a stronger link to vulnerability, adaptation, and societal risk to climate change and climate variability (see also van van Ruijven et al. 2013).

The SSPs consist of three elements: 1) a narrative (van Vuuren et al. 2013); 2) a set of traditional drivers for Integrated Assessment Models (GDP, population, urbanisation); and 3) several indicators that are relevant for research on impacts, adaptation and vulnerability, such as poverty and governance (van Ruijven et al. 2013). The narratives of the five SSPs explore the different potential combinations of challenges to climate change adaptation and mitigation. These narratives range in the extremes from a sustainable world, with low challenges to both mitigation and adaptation, to a fragmented world with high challenges to both. Narratives in between describe a conventional development world and pathways in which either adaptation or mitigation challenges dominate (see O'Neill et al. 2013).

The different criteria used and the underlying assumptions in the SSPs and global modelling approaches need to be evaluated against key information required for vulnerability and risk assessments for both hazards and climate change applications. To begin, it is beneficial to examine how the vulnerability research community could make use of scenarios to underscore that risks due to climate change are not solely dependent on future climatic conditions, but equally dependent on potential changes in societal vulnerability and adaptive capacity (see IPCC 2012, p. 67–90). To illustrate how scenarios can be used to link vulnerability and risk assessment to climate change adaptation, we use two case studies representing a top-down versus bottom-up approach.

4 Scenarios for vulnerability

4.1 Conceptual basis and definitions

It is important to note that the terms vulnerability, risk, and mitigation are understood differently in the Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA) communities (Schipper 2009; Birkmann and von Teichman 2010). The WorldRiskIndex, for example, clearly differentiates between natural hazards (e.g. flood, drought, sea level rise) and the vulnerabilities of a society. In this paper we follow the understanding of vulnerability based on the IPCC special report SREX, which defines it as the propensity and predisposition to be adversely affected (IPCC 2012, p. 564). This definition is commensurate with the understanding applied in the DRR community (United Nations/ISDR 2004; IPCC 2012). In climate change research the term sensitivity is often used to further operationalize vulnerability (e.g. see Tol and Yohe 2007), while in disaster risk reduction terms such as susceptibility and fragility are applied. Susceptibility (or fragility) describes the predisposition of elements at risk to suffer harm and is seen as a sub-component of vulnerability. While sensitivity refers to the degree of responsiveness of an exposure unit to climate change, whether beneficial or detrimental (IPCC 1994). In practice criteria and assessments for susceptibility and sensitivity overlap. Finally, vulnerable people and systems have also capacities to respond to hazards in terms of coping or adaptation. Thus we view coping and adaptive capacities as closely linked to vulnerability (see e.g. the WorldRiskIndex).

4.2 Global top-down: the WorldRiskIndex

The WorldRiskIndex provides a quantitative test case for exploring how scenario data can be incorporated into risk and vulnerability assessments at a global scale using a top-down approach. It is based on this understanding of vulnerability defined above. It views risk as a product of the interaction of a hazardous event with the vulnerability of a society or, using the conventional risk equation, risk is the probability of an occurrence of a hazardous event multiplied by the consequences.

The WorldRiskIndex uses four components in its construction: a) exposure to natural hazards (including frequency and intensity); b) the susceptibility of people and societies exposed; c) their coping capacities; and d) adaptive capacities (Fig. 1). The terms are discussed in detail in the specific sub-sections below (e.g. exposure, susceptibility). The WorldRiskIndex underscores that risks in the light of climate change and natural hazards are not solely dependent on the hazard, but also on the vulnerability of a society including its exposure (see details in the supplement S1). The calculation of exposure includes hazard frequency and yields the number of people exposed to a natural hazard and climate change impacts. The other three components (susceptibility, coping capacity and adaptive capacity) focus on the vulnerability of societies and social actors. The four components include 28 specific indicators (Fig. 1) (Birkmann et al. 2011, and supplements S2, S3). While some indicators of the WorldRiskIndex are found in scenarios for climate change mitigation and adaptation, such as GDP per capita and poverty rates, other indicators that are more specific to the disaster risk context, such as the number of people with hazard insurance, are absent.

Previous versions of the WorldRiskIndex have been based on past and present data in order to calculate present national risk and vulnerability levels. To make the methodology amenable for exploring conditions yet to come, it is necessary to calculate future values of indicators for all the vulnerability components. Those future indicators result from three different scenarios provided by the Pardee Center and generated using the International Futures system (IFs).[1] IFs is a large-scale integrated database and global modelling system

[1] All of the scenario data used is based on the data within the Base Case, Security First and Sustainability First scenarios version 6.68 of IFs. Several of the variables used in this analysis will be available as part of the SSP process. For instance, population, GDP and urbanisation projections on the country level are currently available while other indicators will be produced as output of integrated assessment models (including the IFs) and other approaches. The IFs dataset is currently the most consistently available projection for these indicators.

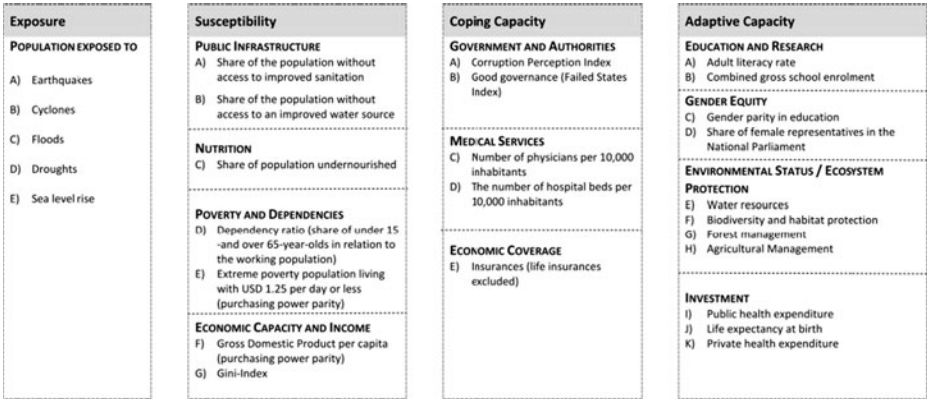

Fig. 1 Indicators used within the WorldRiskIndex

representing 183 national entities (Hughes et al. 2011, pp. 30–32; see also supplements S7 and S8, and IFs project website http://www.ifs.du.edu). The modelling system contains demographic, economic, health, infrastructure, energy, agricultural, socio-political and environmental sub-systems. It is theory and data driven and starts from historical data and draws upon standard approaches to modelling specific issue areas (Mathers and Loncar 2006) whenever possible. The model provides global results with national scale resolution annually from a base year of 2010 for any horizon through to 2100. In recent years, IFs has been used to explore patterns of potential human progress, addressing income poverty (Hughes et al. 2009), education (Dickson et al. 2010), health (Hughes et al. 2011), infrastructure (Rothman et al. 2013), and domestic governance (Hughes et al. 2013). However, scenario data, particularly for the coping capacity and adaptive capacities components (Fig. 1) are not yet available within Integrated Models that run such scenarios at the global scale. As a result, scenarios were only used to calculate the exposure and susceptibility components of the WorldRiskIndex.

Three different scenarios were used for each of the 183 countries for the years 2010 and 2035. The first scenario is the "Base Case" scenario, reflecting a dynamic business as usual path. The second scenario, "Security First", is characterised by governments and private sectors that focus on improving human well-being primarily for the rich and powerful people in society. The third scenario, "Sustainability First", assumes successful collaborations between government, civil society and the private sector to improve the environment and the human well-being taking into account equity, transparency and accountability. In-depth descriptions of these scenarios can be found in the supplement (part S8) to this paper and in the GEO-4 report (UNEP 2007).

4.2.1 Exposure of people

The IFs model generates population scenarios at the country level, but these do not differentiate between people exposed or not exposed to natural hazards and climate change impacts. Future physical exposure (to floods, cyclones, droughts and sea level rise) is mainly determined by the different scenarios of future population growth based on existing hazard and exposure patterns in 2010 (see Welle et al. 2012 and supplements S2, S5).

Increasing average annual exposure related to floods, cyclones, droughts and sea level rise is seen for each continent, with the exception of Europe, where the trend in exposure is reversed beginning in 2025 (see Fig. 2). This downward trend is due to demographic change (e.g. most notably declining populations). Large increases in the number of people exposed to hazards are shown in absolute and relative terms for Asia and in terms of relative increases in Africa. Recent global studies such as the IPCC SREX report support these general exposure trends and global hotspots, particularly with regard to floods and tropical cyclones in Asia (IPCC 2012, pp. 240–241, Peduzzi et al. 2012).

Overall, the findings underscore that exposure scenarios can be developed and these can highlight regions of the world that might experience large increases in population exposure to natural hazards and climate change impacts due to natural population growth and potential migration processes. However, this approach to exposure scenarios has limitations. The most important is the difficulty in calculating specific future hazard patterns. Reliance on projected population growth for hazard zones based on present day may underrepresent the true nature of the hazard zone in the future.

4.2.2 Susceptibility

We define susceptibility as conditions of exposed people or societies that make them more likely to experience harm and to be adversely affected by a natural hazard or climate change. Hence, susceptibility is a key characteristic of the propensity to be adversely affected.

Changes in susceptibility can be measured in absolute or relative terms. In absolute terms, most countries can be expected to see improvements, i.e. their susceptibility will fall over time. However, the rate at which this occurs will likely differ by country. Past crises and disasters clearly show that societal conditions make a significant difference in terms of harm and loss experienced in such events (IPCC 2012). While the indicators can help to identify countries with a high level of susceptibility, they cannot predict the impact of individual disasters. Relative levels of susceptibility permit comparisons between countries and show shifts that could reflect the rate of change or the nature of exposure.

All seven indicators used to measure the susceptibility of societies and people exposed can be calculated using the IFs model (see supplements S1–S6 and Fig. 1). Indicators such as

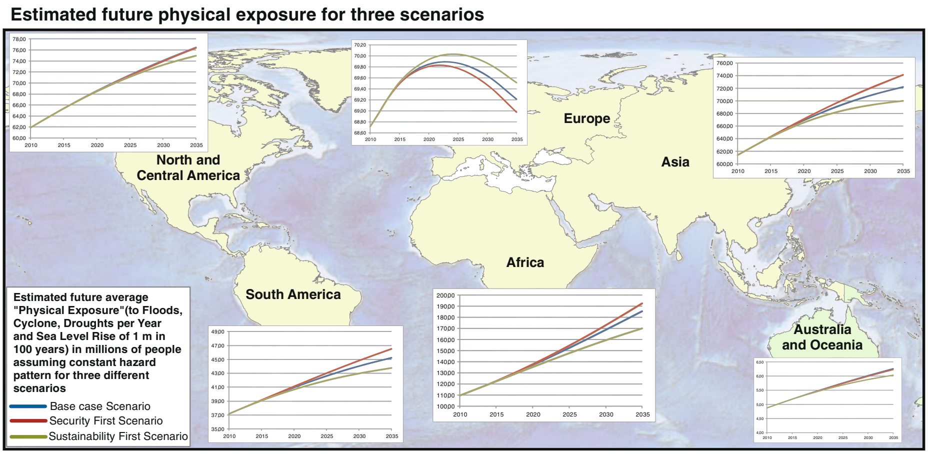

Fig. 2 Changes in the exposure of people (in millions) per continent to natural hazards and climate change impacts based on three different scenarios (Base Case (*blue line*), Security First (*red line*) and Sustainability First (*green line*)). Source: own map based on data from PREVIEW and Pardee Center

for poverty (population living on $1.25 USD per day) or the dependency ratio and the Gini index are key proxies for estimating vulnerability to natural hazards and climate change impacts. High levels of poverty and a large proportion of elderly and young people compared to the population in working age as well as a very unequal distribution of wealth (Gini Index) within a country increase the likelihood that extreme events and hazards have significant negative consequences (see supplement S1). The results shown in Fig. 3 support the key findings of the WorldRiskIndex in 2011 (Birkmann et al. 2011; Welle et al. 2012). The calculations highlight that global hotspots of susceptibility are, at present, located primarily in Africa, South Asia, South-East Asia and Latin America.

The scenario data show important dynamics in relative susceptibility at a global scale (Fig. 4). For example, the analysis reveals that the three scenarios differ for Bolivia and Pakistan. Bolivia remains in the medium susceptibility class in the "Base Case" and the "Sustainability First" scenarios, although some indicators such as population without access to sanitation and without access to clean water are quite different in these scenarios. In contrast Bolivia is classified as highly susceptible in 2035 in the "Security First" scenario, due to an increase in the percentage rate of people without access to improved sanitation (43 %) followed by the high percentage of people undernourished (13 %) and a low GDP compared to the values in the other two scenarios. In contrast Pakistan is classified as highly susceptible in the "Base Case" and the "Security First" scenarios in 2035. Under the "Sustainability First" scenario, however, Pakistan improves its conditions and shifts into medium susceptibility, primarily due to a lower percentage of people living in poverty and a reduction of the population undernourished. In addition, the "Sustainability First" scenario reveals a significant reduction of susceptibility for various countries within Africa such as Mali, Niger, Tanzania and Benin compared to the "Security First" and the "Base Case" scenarios (see Fig. 4).

If we compare all three scenarios, "Base Case", "Security First" and "Sustainability First", using World Bank income groups (World Bank 2013) we see significant differences in the levels of, and changes in, absolute susceptibility between these country groups (see supplement S6).

Susceptibility using the Base Case scenario 2010

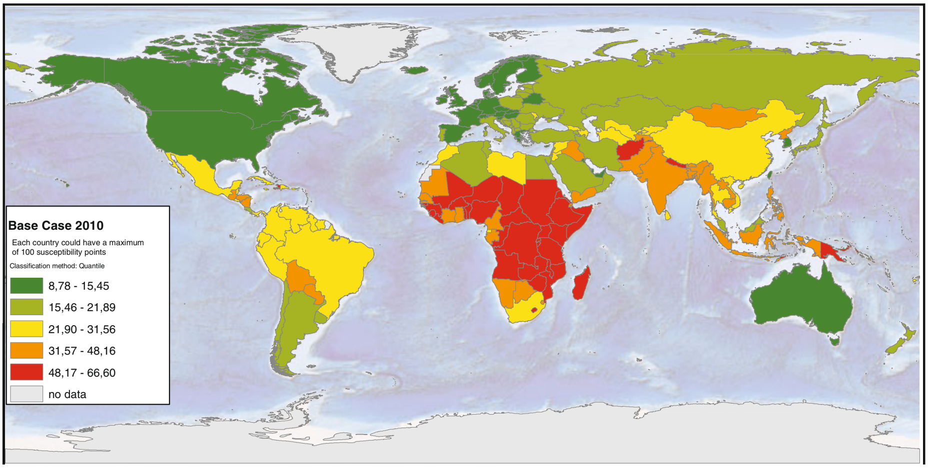

Fig. 3 Present susceptibility and its global distribution using the methodology of the WorldRiskIndex. Source: Own map based on the WorldRiskIndex (see Birkmann et al. 2011 and Welle et al. 2012) and data of the Pardee Center (see Hughes et al. 2011)

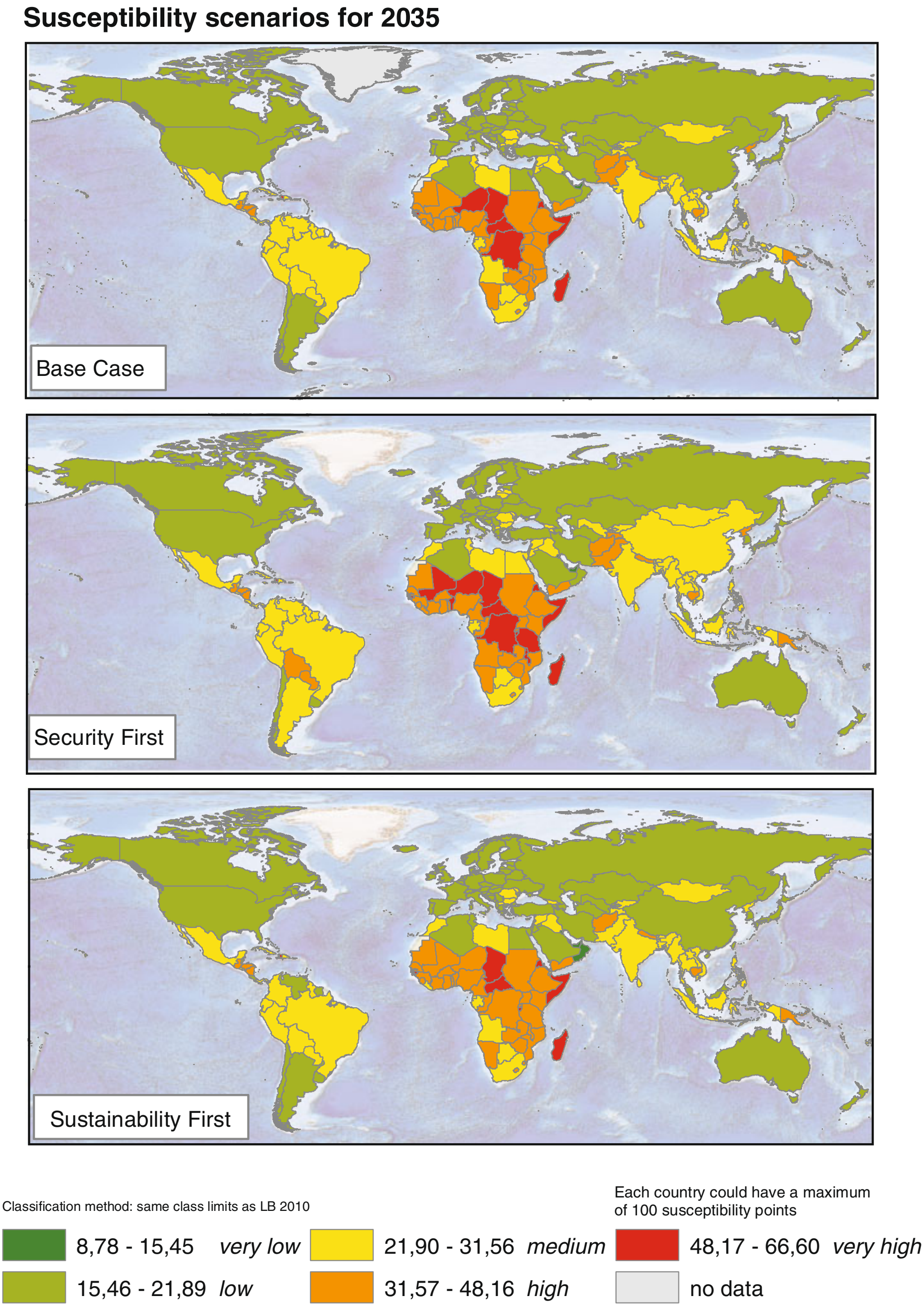

Fig. 4 Scenarios for susceptibility for the year 2035 using the WorldRiskIndex indicators

Overall, the application of scenario data to a global risk assessment tool (WorldRiskIndex) is feasible. It shows some interesting differences in terms of future relative susceptibility of countries and between different country income groups. Limits and constraints are discussed in the final part of the paper. While global quantitative index and modelling approaches are often developed by experts such as illustrated above by the WorldRiskIndex, local and qualitative scenarios have different functions aiming for the co-production of knowledge and the integration of stakeholder knowledge and values (Jones and Preston 2011).

4.3 Local bottom-up: Jakarta, Indonesia

A local participatory – bottom-up – scenario approach for the city region of Jakarta in Indonesia is used as a contrasting example of scenario approaches. The results are based on a workshop of the 8th meeting of the UNU-EHS Expert Working Group on Measuring Vulnerability in Indonesia in July 2012 involving international, national and local experts (see supplement S9 and website UNU-EHS). The case study illustrates how local approaches using qualitative data are structured and what kind of information they can provide for vulnerability and adaptation assessments.

Jakarta is one of Asia's megacities most exposed to natural hazards, notably flooding. Future exposure and susceptibility patterns depend heavily on the socio-economic development pathways of the city, which are in turn linked to land subsidence, urban sprawl, and social development. Jakarta serves as a prime example for exploring the connections between local urban development pathways and vulnerability trends through scenarios.

4.3.1 Methodology

Participatory and qualitative scenario processes often contain three phases: a preparation phase, the scenario development phase, and an evaluation or testing phase (Glenn et al. 2009; Gordon 2009). Participatory scenario planning is not new, and has been applied for example in the context of sustainable development research (Khakee 1999). However, participatory scenario development differs from participatory community risk assessment (van Aalst et al. 2008) in the sense that it goes beyond the analysis and discussion of past and present trends, and incorporates likely future ones.

Based on the workshop with international, national and local experts and stakeholders (see supplement S9), a multi-dimensional concept of urban development and adaptation was outlined, mainly focusing on key variables and trends of social, economic, ecological and institutional issues linked to vulnerability, risk and adaptation. The scenario development followed the three phases outlined above and is described in detail in the supplement (see supplement S9). The moderators defined one axis as scenarios of adaptive versus non-adaptive development in the context of climate change. The second axis was defined by local and national experts and practitioners based on current development patterns and future visions. The four-scenario spaces are based on these two axes (see Fig. 5).

4.3.2 Findings

The discussion of the indicators and criteria to visualize an increasing or decreasing vulnerability and respective trends, such as poverty, migration, income inequalities, role of Forgein Direct Investement (FDI) (see Fig. 5) was done jointly and respective topics, indicators and criteria were mapped on a white board. This allowed a transparent and understandable scenario discussion. The documentation and visualisation was also helpful in the sense that contrasting alternative scenarios for Jakarta could be checked and critically reviewed by other participants (third phase of scenario construction). Figure 5 shows

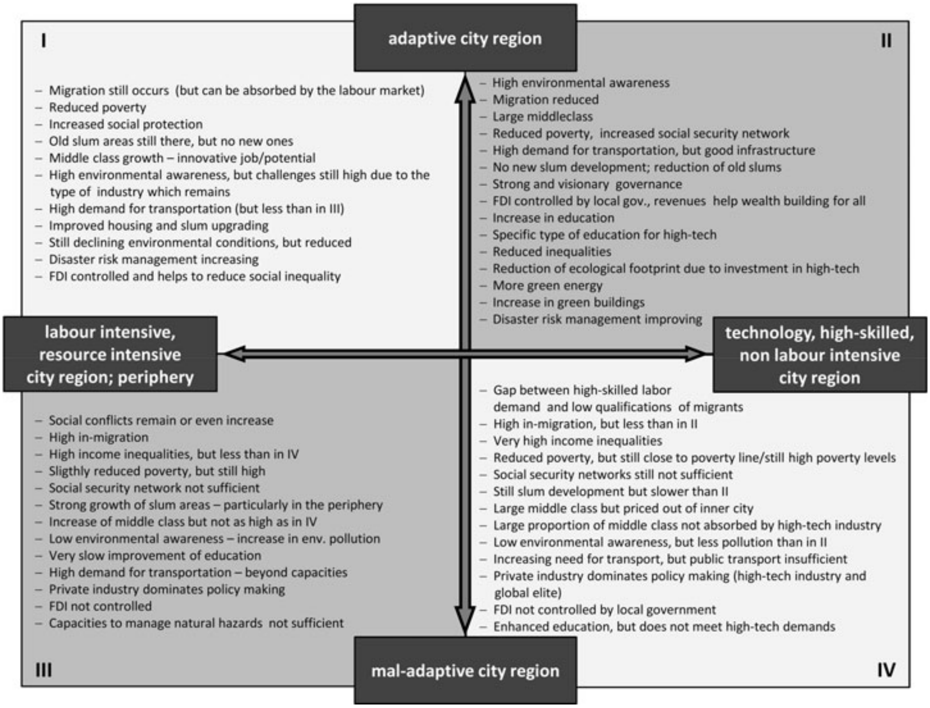

Fig. 5 Participatory scenario development—case study Jakarta

different trends and core characteristics associated with vulnerability and adaptive capacity. In contrast to the quantitative global approach that resulted in precise numbers and measurable indicators, the participatory scenario method in Indonesia provided contextual information regarding core characteristics and trends of vulnerability - including adaptive capacity - under different scenarios. Since the experts and stakeholders in the excersise had different backgrounds and only limited statistical expertise, the assessment did not aim for developing a specific set of data or measurement guidelines. However, the participatory scenario discussion encompasses indicators and criteria for vulnerability that are now, after the workshop, being examined in terms of data available (see supplement S9.1). The ongoing cooperation with Indonesian scientists shows that respective data can be gathered, however, the type of assessment and the results are quite different from a quantitative approach. That means the core result of this assessment is a vulnerability profile narrative, one with alternative futures. For example, the results reveal (see Fig. 5) that migration, poverty, social security, labour, energy use and governance were key themes identified as shaping the future and hence were used to judge whether the city region will develop into a more adaptive or more mal-adaptive direction. The terms adaptive and mal-adaptive were used as broader categories, yet there was consensus that the criteria and indicators developed are also characteristics of vulnerability (such as poverty, income inequalities etc.). Often, similar issues, but with different trend directions and magnitudes (e.g. in-migration) were discussed regarding the different scenario spaces. The findings underscore that the vision of a high-tech city with non-labour intensive industries is not necessarily an adaptive city-region where people are less vulnerable. If present trends regarding in-migration and poverty cannot be reversed, a high-tech city might even lead to higher vulnerability, since the gap between high skilled labor demand and in-migrants with low qualifications might be intensified (see Fig. 5, scenario IV). While storylines or narratives in the SSP process also encompass a description about future vulnerabilities, the locally-derived vulnerability profiles here are often directly linked to experiences in the past and the local knowledge of stakeholders and experts involved.

The participatory development of qualitative local scenarios contributes an important option to enhance not only the thematic focus but also the methodological toolkit for exploring future vulnerability and risk. The participatory bottom-up approach offers a venue for different stakeholders to jointly discuss key trends that are likely to shape the future (see more details in the supplement S9). Also normative aspects, such as the question "what is a desirable future?" were discussed during the process. However, the exercise also shows that local participatory scenarios are often limited in terms of capturing temporal dynamics or timelines compared to quantitative top-down scenarios that are based on extrapolated data (see e.g. Fig. 2). The participatory scenarios, however, do show future trends based on local desires and expectations, but these are less exact in their measurement. The development of local scenarios reflects specific place-based knowledge that does not necessarily provide a comprehensive or all-embracing picture.

Certainly disagreements and different judgements amongst the experts remain a challenge for assessing the validity of single scenarios and for generating a coherent overall scenario framework. However, in the spirit of focus group discussions, such disputes also proved highly informative and added a rich context to the scenarios.

5 Discussion and conclusions

Overall, the juxtaposition of two methodologically different approaches (top-down and bottom-up), using two very different scales, underscores the broad spectrum of applications of scenario techniques in research into vulnerability, risk and adaptation. While global quantitative scenario approaches on exposure and susceptibility allow for exploration of large-scale trends and patterns, the local qualitative and participatory approach enables researchers and practitioners to understand, examine, and discuss the links between global or sub-national trends (e.g. SSPs) and the vulnerability in specific regions or municipalities. The two approaches contain very different epistemologies and methods, however, a key similarity is that both allow for an examination of present and future trends in vulnerability under different scenarios and hence provide a thinking tool about the drivers that shape potential future conditions. Qualitative approaches provide broader contextual details on future patterns of vulnerability and disaster risk to climate change and extreme events (e.g. reduced poverty, high in-migration), while quantitative approaches allow for a more detailed analysis or visualization of trend dynamics within a specified time period (see e.g. Fig. 2).

The visualisation of scenarios for population exposure to natural hazards and climate change impacts as well as the scenarios for susceptibility in the year 2035 show that socio-economic development pathways and demographic change (e.g. in Europe for example) are important factors in determining different levels of susceptibility and exposure in various scenarios. The hypothesis that elderly people are more susceptible to hazards influenced by climate change (e.g. heat stress, floods) compared to people in the working age is, however, based on present knowledge. It is defined through the choice of indicators to estimate vulnerability (see supplement S1). It is very unlikely, but still possible, that technical and medical innovations in the long-term would change this difference in susceptibility between elderly and working-age people. Consequently, uncertainties and limits of predictability apply to different types of causal-relationships in vulnerability studies and selected indicators.

Nonetheless, the anticipation of different trends and development pathways within various scenarios embedded in risk and vulnerability assessments enhance present approaches and strategies. Various disaster risk reduction strategies are still characterised by a dominant focus on present socio-economic conditions—particularly present vulnerability profiles. In contrast, scenario approaches like the ones presented here (top-down or bottom-up) can, in principle, provide a lens to think about future conditions and those factors that will modify vulnerability.

Most notably, the analysis of susceptibility in the year 2035 for the three scenarios shows significant changes in Asia (China, Pakistan, etc.), Africa (e.g. Democratic Republic of Congo) and Latin America (e.g. Bolivia). These changes are determined by different factors, but can be examined in more detail for policymaking. The different scenario results for China or Pakistan, for example, underscore that socio-economic conditions and shifts in properties such as demographic structures or poverty levels at the national scale are significant drivers of vulnerability and might also heavily influence sub-national and local vulnerability conditions. However, the precise interpretation of the different country results is still a challenge and uncertainty remains, for example with regard to whether these countries are more likely to develop in the direction of the *base case*, the *security first* or the *sustainability first* scenarios. In addition, the driving forces of vulnerability might change over time meaning that some additional factors that are not yet sufficiently identified can have an important effect on vulnerability in 2035. Consequently, the timeframe of the scenarios and the different assumptions have to be considered when they are applied in policymaking.

However, scenarios can help shaping future-oriented policies for disaster risk management and climate change adaptation by anticipating likely conditions in terms of exposure or susceptibility at some distant time. An added value of the overall approach is that the model results and scenario expertise of the Integrated Assessment Modelling (IAM) community is used within tools for vulnerability and risk assessment. But comprehensive data sets for assessing future scenarios for coping and adaptation is still lacking. Therefore, an important constraint to present scenario construction is the limited data for modelling coping and adaptation as shown in the example of the WorldRiskIndex.

Compared to the global quantitative scenarios, local participatory scenarios capture coping and adaptation challenges through qualitative data based on the experiences and knowledge of stakeholders involved. As shown in the Jakarta example, participatory, local approaches can be thematically much broader and place-specific; however the trends and criteria used also depend heavily on the composition of the participants and experts in such scenario exercises. In contrast to quantitative approaches, these qualitative scenarios (see Fig. 5) often do not capture temporal dynamics, a clear constraint in their application for policy making. In general, bottom-up approaches provide a process for discussing different potential futures linked to the experiences and expertise of the stakeholders involved.

There is great potential for linking global and local scenarios. Scenarios at the local level need to be informed by potential global trends and development patterns, such as regional economic growth or population growth. In contrast, local scenario approaches check the relevance of the topics and indicators used at the global level to describe susceptibility and exposure. In addition, they might also raise awareness about new and locally specific issues that need to be addressed when thinking about future development trends in vulnerability, risk and adaptation at the local level, such as issues of migration and the performance of natural hazard management (see Fig. 5). However, as shown in the test cases, the linking of different scenario methods (qualitative versus quantitative) and bridging the different scales is challenging. Some relevant trends and indicators at the local scale cannot be applied for the identification of different levels of vulnerability and risk at the global scale and vice versa.

The case studies provide valuable lessons with respect to future development and application of the Shared Socio-economic Pathways (SSPs). To maximise their utility to diverse research communities and disciplines, the SSPs should remain sufficiently flexible to inform both top-down global scale scenario, development-based quantitative indicators as well as bottom-up, participatory scenarios that are more qualitative in nature. The development of quantitative, national-scale indicators by the IAM community as part of the SSP process creates opportunities for expanding tools such as the WorldRiskIndex to accommodate a greater array of alternative development pathways. However, the Jakarta case study illustrates that local aspects of societal development and normative considerations of actors are equally important in developing legitimate scenarios.

6 Future research

Future research needs to focus on improving the links between different scenarios and assessments at different scales as well as the improvement of data for capturing societal response capacities to hazards and climate change. More precisely, research has to examine the mechanisms for bridging the various scenario approaches across different spatial and temporal scales as well as in terms of different methods used (qualitative versus quantitative, top-down versus bottom-up). In addition, it is essential to improve the data bases for capturing coping and adaptation processes that have not sufficiently been captured in existing global models. This paper provides a first step towards a better understanding on how scenarios might enhance present risk and vulnerability assessment tools. However, further studies are needed that also address specific stakeholder and user groups in DRR and CCA.

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