Improving research across scales: the shared socio-economic pathways

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Population is an important component in the scenario-based assessment of global change, exposure and vulnerability to climate risks, and sustainability. The spatial distribution, as well as demographic and socio-economic characteristics of the population, will influence the degree to which humans impact, and are impacted by, global climate change. Existing global change scenarios, such as the widely used IPCC SRES scenarios [1], generally include limited socio-economic information (e.g., population, GDP) aggregated at the national or regional level, and the corresponding narratives describe alternative socio-economic futures in a very broad sense. Producing sub-national and/or local scenarios that can be explicitly linked to existing global scenarios has proven challenging, and the few existing SRES driven sub-national scenarios often lack the desirable level of spatial and socio-economic detail for impacts, adaptation, and vulnerability (IAV) research at the local level. As the guidance paper notes, there is currently no shared set of perspectives about world socio-economic futures that correspond to global climate change scenarios [2], and much of the existing IAV work is based on local scenarios that are not informed by or linked to large-scale socio-economic and/or climate change scenarios. As such, much of the existing gap between mitigation/adaptation research can be attributed to the lack a consistent scenario framework that is applicable across multiple scales. The new shared socio-economic pathways (SSPs) offer an opportunity to address many of structural problems by providing global scenarios and narratives that are scalable and relevant to the mitigation and adaptation perspectives.

Through the SSP database population data, including gender, age-structure, educational attainment, and urban/rural status, as well as GDP (PPP) are currently available for each of the five SSPs in five year intervals (2000-2100) at the regional (32 world regions) and national-level [3]. These quantitative projections reflect global narratives that have been extended to the regional/national scale which are indicative of the widely varying societal trends that will result from alternative global futures. For example, an SSP 4 world (inequality; adaptation challenges dominate) will lead to very different types of societal changes, and subsequently qualitative trends in socio-economic indicators across countries in, for example, Western Europe and Sub-Saharan Africa. Already this represents an improvement over the existing SRES scenarios in which there was no systematic methodology for producing national-level quantitative projections of GDP and population. However, in addition to aggregate national projections consistent with the global narratives, it is important that we consider the needs of the IAV community as they relate to spatial resolution of the data. Whereas climate modelers working at the global scale often work at coarser resolution, local/city-based IAV research typically requires population/socio-economic data at higher resolution. It will be important to consider how to further downscale projections from the national to the local level in a manner consistent with existing narratives to facilitate locally-based IAV research informed by, and that can inform, large-scale global change research. To elaborate on this issue, and illustrate how the SSP framework can contribute to integrating research across scale I will briefly comment on the development of spatial population projections and their subsequent use in risk, exposure, and vulnerability research.

Spatial Population Projections

It is generally accepted that changes in the size and spatial distribution of the population, particularly in regions experiencing rapid growth and urbanization, will have significant ecological and socio-economic implications. Assessing these implications requires plausible alternative projections of spatial population distribution that are consistent with the global change narratives describing changes in other characteristics of society that could affect spatial outcomes, such as economic development, policy changes, and changes in the energy system and demand for land. In turn, spatial population change can affect other aspects of society. For example, it is a significant driver of land-use/land-cover change, both directly through conversion to residential, commercial, and industrial uses, and indirectly as increased food demand drives conversion to agricultural uses [4, 5, 6]. Rapid urbanization in many world regions is a significant threat to protected areas, sensitive habitats, and biodiversity [7], and projections of spatial change are crucial to identifying potential future environmental hotspots [7, 8].

Cities and urban agglomerations exert significant pressure on climate, land, and hydrology at local, regional, and global scales [9]. Invariably, city growth and the corresponding expansion in urban land is driven by population growth. Rapidly improving satellite data has led to a substantial amount of recent parallel work related to defining and projecting the spatial extent of urban land cover [9, 10, 11], work often informed by, or used as an aid in, projecting spatial population. In addition to land-use change, alternative forms of urban development have varying implications for energy demand and emissions [12, 13]. Projections of spatial emissions of greenhouse gases and air pollutants often rely explicitly on spatial population data [14, 15]. Similarly, estimates of both the size and spatial orientation of populations are crucial to planners that must ensure adequate access to food, water, energy, and public services while attempting to reduce vulnerability to climate-related hazards [16, 17, 18, 19].

The SSPs provide both the structure and data necessary to produce a consistent set of alternative spatially explicit population projections that reflect the socio-economic space implied by global narratives. Scenario-based national-level projections of population (including the characteristics of the population noted earlier) and GDP have been created for each of the SSPs. However, additional work is necessary to determine how best to downscale these data to the sub-national level in manner consistent with the associated narratives.

There were several attempts to construct spatially explicit projections of the future population that were consistent with the SRES scenarios [20, 21, 22]. However, most of these projections were constructed using scaling techniques or trend extrapolation, and national-level aggregate population projections were not consistent for each scenario across all models[1]. By definition these projections reflect a future world in which the spatial population structure does not change, or changes only through continuation of the most recent sub-regional trend, and therefore do not reflect the futures implied in the global narratives. In our work we have been testing an alternative method for downscaling spatial population projections (including urban/rural classification) with the SSPs in mind [23]. We employ a gravity-based model in which aggregate population projections are downscaled from the national/sub-national level to grid cells, introducing free parameters into the model that can be calibrated to reflect patterns of spatial change in historical data and altered if desired to reflect varying assumptions regarding socio-economic futures. The model is applicable at varying scales of spatial analysis, treats urban and rural populations as separate yet interacting entities, and includes mechanisms for correcting edge-effects and limiting habitable land area.

As noted early, existing regional/national-level quantitative projections of key socio-economic indicators are consistent with the five global scenarios and corresponding narratives already exist. Extending these narratives and projections to the sub-national/local level requires a mechanism for linking storylines to the downscaling procedure. In the gravity-based model for downscaling population we employ free parameters that can be calibrated to reflect certain patterns of spatial development, and as such can produce spatial distributions indicative of certain local qualitative patterns implied by and consistent with global narratives. For example, consider once again an SSP 4 world in which economic growth and technological change/diffusion are fragmented and unequal. In lower income countries population growth rates remain relatively high and urbanization occurs rapidly. By contrast the

[1] The SRES scenarios included larger regional population projections but no national projections. In many cases researchers came up with their own methods to extract national-level estimates for purposes of downscaling.

developed world experiences slower growth (or decline) and fairly stable urbanization rates. One could imagine such a scenario leading to very concentrated patterns of urban growth in developing countries as people move towards urban areas in search of work, but due to relatively slow investment in infrastructure and technology are forced to live very close to their places of employment. Conversely, the developed world may be marked by patterns of slow urban expansion or the development of smaller urban nodes, de-concentration in city-centers, and rural decline.

Ideally the SSPs will facilitate the development of a set of spatially explicit global projections at high resolution in which local patterns of change are based on a set of internally consistent narratives operating at multiple scales. As an input to locally-based IAV research such a data set would aid in overcoming existing limitations in cross-study comparisons. Furthermore, including these data in global-scale climate research may aid in assessing uncertainty in climate outcomes associated with alternative socio-economic/population futures. Significant challenges remain in completing this process however, including developing methods for producing high resolution projections that include gender, age-structure, and educational attainment, as well as downscaling economic projections. These characteristics are important factors affecting exposure and vulnerability to climate-related hazards.

Using spatial population to assess vulnerability to climate-related hazards

Climate change risks are a function of the nature of physical hazards related to climate as well as the exposure and vulnerability of society and ecosystems to those hazards [24]. Within the global change community research has tended to focus on characterizing potential changes in the frequency and magnitude of physical hazards, including floods, droughts, heat waves, intense precipitation, and tropical cyclones. Possible changes in future vulnerability and exposure have historically received less attention, but recognition of the importance of this dimension is growing, as evidenced by the treatment of risk and vulnerability in the IPCC Special Report on Extremes [24], the forthcoming Working Group II report of the IPCC Fifth Assessment Report, and the SSPs which explicitly recognizes the role of vulnerability in determining climate change risk [25].

Vulnerability[2] itself can be viewed as a function of the exposure and sensitivity of society to hazards as well as its capacity to adapt [24]. All three of these aspects will change over time, leading to substantial uncertainty in future climate risk. A key research task is to understand how large this uncertainty might be, and what its main determinants are, in order to better inform priorities for research and risk management strategies. The SSPs provide a framework for understanding and assessing the importance of alternative socio-economic futures as they relate to uncertainty in exposure and vulnerability to climate risks as both are a function of the spatial distribution of the population as well as characteristics of that population. The former drives exposure to climate-related hazards while the

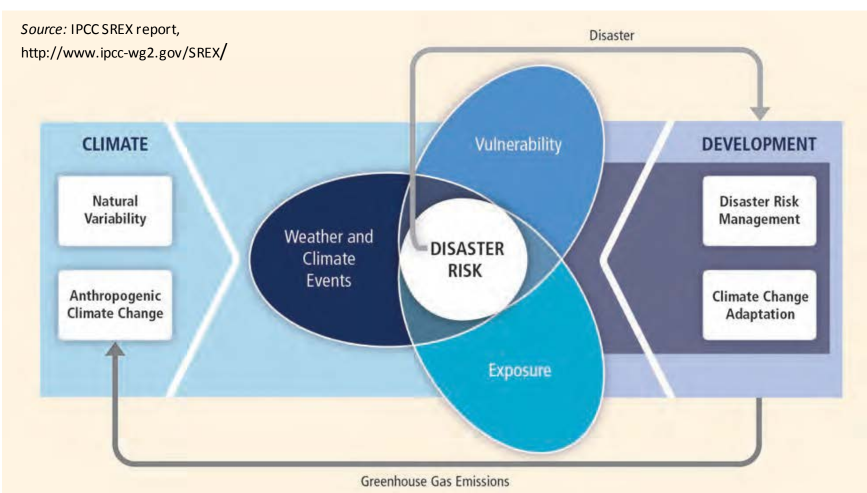

Figure 1. The importance of exposure and vulnerability to climate-related hazards to risk management and sustainability.

2 Definitions of vulnerability vary widely in the literature [26]. In some cases, as shown in Figure 1, vulnerability and exposure are defined separately, while in many cases exposure is considered a component of vulnerability.

latter determines vulnerability to those hazards through adaptive capacity. Furthermore, feeding alternative socio-economic futures (and the corresponding spatial distributions) into global climate models may shed additional light on the consequences of such futures as they relate to mitigation, information that would certainly be of interest to planners and policy makers.

Conclusions

In the development of the SSPs experts have recognized that successful integration of the mitigation/adaptation perspectives requires a two-way interaction in which we think not only about how IAV analyses can incorporate global scenarios in their approaches and methods, but how global scenarios can be developed to meet both the needs of IAV researches *and* incorporate findings from local analysis [2]. The traditional top-down approach, in which local scenarios are a function of broader global scenarios is important, but equally so is the bottom-up perspective in which global narratives are sensitive to findings at the local level. This commentary has focused primarily on the IAV perspective, noting examples where the structure provided by the SSPs enables integration of research across multiple scales. Historically cross-study comparison of IAV work has been confounded by often disparate methodologies, data sets, and temporal and spatial scales. From the perspective of the population environment community the SSPs represent an opportunity to adopt a uniform framework for IAV assessment, as such researchers should be aggressive (yet realistic) in suggesting methodological improvements in the production of quantitative projections, and lobbying for the future inclusion of additional important data.

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