Differential Vulnerability to Natural Disasters according to the IPCC Shared Socioeconomic Pathways (SSPs)

Erich Striessnig

Wittgenstein Centre for Demography and Global Human Capital (IIASA, VID/ÖAW, WU),
International Institute for Applied Systems Analysis

Abstract

Despite growing evidence on the human impact on the climate system, the specific effects of already unavoidable climate change in specific locations on future human well-being are still uncertain. The present paper studies the hypothesis that early investments in universal primary and secondary education around the world are possibly the most effective strategy for empowering people to cope with the still uncertain dangers associated with future climate conditions. Building on latest empirical evidence from cross-country time series of factors associated with past natural disaster fatalities since 1970 in 152 countries, the paper first illustrates statistically the central role of education in both increasing the coping capacity with regard to particular climate related hazards and improving the resilience of people to climate risks in general. In the second part, this evidence will be translated into projections of the future impact of climate-related natural extreme events using five demographic scenarios as defined by the narratives of the Shared Socioeconomic Pathways (SSPs). By considering not only the projected population size but the full population heterogeneity by age, sex and level of education, these narratives go well beyond what the Intergovernmental Panel for Climate Change (IPCC) used in their previous SRES scenarios for assessing future climate impact. The results will be presented in terms of predicted numbers of deaths for five major world regions and show that considering the effect of education makes a significant difference.

Introduction

Vulnerability to natural disasters is of significant interest in its own right as an important source of premature death. But it becomes even more relevant when we consider that the mechanisms by which such vulnerability is either enhanced or reduced coincide with those that affect the resilience or vulnerability to likely future climate change. Vulnerability towards natural disasters affects people at all stages of their life course. While there is some evidence that people at the very beginning and at the very end of their life cycle are more vulnerable because they directly depend on the help of others, for the years in between other factors tend to dominate the differentiation of risk. These factors range from household characteristics associated with economic standing (such as the construction and stability of the house) to the ecological setting of the house to individual behavioral variables. One individual characteristic that in the past has not received enough attention in risk studies is the level of educational attainment. Recently a series of studies has clearly demonstrated the decisive role of education in reducing such risks.

In general, in the field of population-environment interactions there is increasing recognition that people not only differ with respect to their contribution to climate change but also in their adaptive capacity. The future adaptive capacities of societies and the differential vulnerability of their members are one of the least studied aspects of the important question of how dangerous climate change will be for future human well-being. For example, several studies that try to assess the impact of climate change on future malaria deaths in Eastern Africa combine the projected changed climate conditions for 2080 with today's public health capabilities, population distributions, human capital, and general adaptive capacities. But such assessments can be misleading since we know that not only will the climate likely change over the coming decade, but also that demographic structures and associated socioeconomic capabilities will definitely change.

To study the interactions of socioeconomic development and societies' resilience to climate change in greater detail and also to provide a scenario ''thread'' through the different climate research communities (van Vuuren et al. 2011), the global Integrated Assessment Modeling (IAM) community together with the Impacts, Adaptation, and Vulnerability (IAV) community has recently launched a new scenario development effort (Kriegler et al. 2012) which lead to the so called Shared Socioeconomic Pathways (SSPs). These SSPs are representative narratives of how the world might develop over the course of the 21st century following a widely negotiated and broad enough range of possible alternative futures, particularly with regard to future societies' capacity for mitigation and adaptation to climate change (Brian C O'Neill et al. under review in GEC). The SSPs form the skeleton of the IPCC 5th Assessment Report. Following these narratives, researchers can integrate and make their knowledge comparable across a range of different fields, thus broadening the scope of our knowledge about the likely future implications of climate change.

The original narratives underlying the SSPs have been translated into the language of demographic change by KC and Lutz (2014). Uncovering the “human core of the SSPs”, the authors provide comprehensive assumptions for the future of fertility, mortality, and migration for all countries of the world. As has been pointed out by Hunter and O’Neill (2014), these can be used to look at which demographic factors and relationships can be reliably projected quantitatively into the future. If we know how future population will be distributed across social groups and if we know their vulnerability, we can make projections based on the SSPs. Some examples of such translation attempts include the use of the SSPs for projecting future GDP per capita (Crespo Cuaresma under review in GEC), assessing urbanization impacts from the different scenarios (Jiang and O’Neill under review in GEC), or to the likely damage and adaptation costs due to expected future sea level rise (Hinkel et al. 2014). This particular paper presents a similar translation of the SSPs, namely in terms of future vulnerability to natural extreme events. Applying earlier results by Striessnig et al. (2013) quantifying the demographic determinants of past social vulnerability on the global level, I project the SSPs for Latin America and the Caribbean, one of the world regions most heavily affected by the potential effects of climate change.

Education and Vulnerability

The central hypothesis to be addressed in this paper is that education can play an important role in reducing the negative impacts of climate change on future disaster-related mortality. Recent evidence on both direct and indirect effects of formal education on adaptive capacity, stems from empirical analysis ranging from individual-and household-level studies to village-level studies and national case studies, as well as global-level time series analysis.

An individual level study of disaster preparedness during the 2012 Indian Ocean earthquakes among households located along the Andaman coast in Phang Nga province, Thailand finds that formal education – measured at individual, household, and community level – increases the likelihood of preparedness actions being taken (Muttarak and Pothisiri 2013). While having been affected by the 2004 tsunami clearly increases emergency preparedness, education turns out to be a relevant factor in anticipating the risk and taking preparedness actions for the group of persons without such disaster experience.

Frankenberg et al. (2013) examine the extent to which education serves as a means of protection against natural disaster at the individual level using longitudinal survey data collected in two provinces on the island of Sumatra, Indonesia, before and after the 2004 Indian Ocean tsunami. They find that education clearly plays a role in coping with the disaster over the longer term with the better educated being of better psycho-social health five years after the tsunami. They are less likely than others to live under precarious living conditions and appear to be better at compensating for loss of income following the tsunami.

Similar evidence on the association between education and vulnerability has been reported at the community level. KC (2013) finds strong effects of education using comprehensive village level data in Nepal (a microsample of the 2001 census covering 2.5 million individuals together with disaster data for 2000-2009) on damages due to floods and landslides in terms of human lives lost, animals lost, and other damage to households. Comparing the effect of education with those of income and wealth, the author concludes that education has a stronger and more consistent impact in reducing damage due to floods and landslides in Nepal.

A comparative study by Wamsler et al. (2012) on two low-income settlements in Brazil and El Salvador where climate-related disasters are recurrent yields similar conclusions. The level of education is found to be negatively correlated with the level of risk people are exposed to in the respective area, whereas the causal reasons for this correlation come out to be both direct, by reducing existing risks through i.e. greater awareness and better understanding, as well as indirect, mitigating against aspects that increase risk like poor health, organized crime, teenage pregnancy, single motherhood, or informal settlement growth. In addition to that, they find evidence that education may be key for accessing another prime coping strategy in adapting to climate change, namely migrating out of the affected high-risk area. (Adger and Adams 2013) Evidence on environmentally induced migration from Mali and Senegal strongly confirms this finding. (van der Land and Hummel 2013)

Another study by Garbero and Muttarak (2013) investigates the impacts of floods and droughts on community welfare in Thailand. Based on the Thai government surveys of living conditions and life quality of 68,695 rural villages for 2009-2011, the paper uses difference-in-difference methods to analyze how floods and droughts in 2010 affected consumption and income of the villages in 2011. It finds that communities with higher educational attainment did not experience a reduction in consumption, investment in agriculture, or a decline in income. A further analysis demonstrates that communities with high levels of education are more able to secure available government financial aid for areas affected by floods and droughts.

Again building on the evidence from the 2004 Indian Ocean Tsunami, a study by Muttarak et al. (2012) on 286 villages in Phang Nga province in Thailand, chosen for its most severe losses, shows that preparation for extreme climate events and natural disasters are driven by past experience and anticipation of such events in the future. In addition, villages with a higher proportion of village members with at least secondary education are more likely to prepare for potential natural disasters.

Likewise, Pichler and Striessnig (2013) use data from qualitative interviews conducted in Cuba and the Dominican Republic to compare these two island states with regard to disaster vulnerability. Even though they are fairly similar in their exposure to natural extreme events, disaster outcomes vary greatly between the two islands. While effective disaster response is strongly embedded in the entire Cuban population, which is one of the most educated in the developing world, the interviews strongly confirm that lack of education and literacy in the Dominican Republic makes people more vulnerable and prevents them from even understanding warnings about upcoming danger.

Using national level time series of disaster fatalities around the world, a recent study by Striessnig et al. (2013) finds significant evidence for the role of education – particularly female education – in reducing disaster fatalities while there is no evidence for the widely assumed role of income per capita in reducing vulnerability after controlling for other key determinants of socio-economic development as well as exposure to risk. Table 1 shows an update of this multi-variate statistical analysis with newer data for a larger number of countries (158) and a larger number of alternative models for the period 1970 to 2010. The dependent variable is the log of disaster deaths. The sources of data and definitions of variables are explained in detail in Striessnig et al. (2013). Here it suffices to say that in addition to controlling for the number of disasters (as a proxy for exposure) and for population size as a scale parameter, the rate of population growth (for demographic change), and a polity score (for quality of governance), the different models have been defined to assess the relative importance of three different factors of human development: Economic growth (as measured by GDP per capita), the development of public health (as best captured by lagged infant mortality to avoid endogeneity) and the proportion of women aged 20-39 with at least secondary education (a human capital indicator that has been shown to be most sensitive in other contexts).

Table 1. DETERMINANTS OF NATIONAL DEATH FROM NATURAL DISASTER. PANEL REGRESSION FOR 158 COUNTRIES OVER 10-YEAR INTERVALS BETWEEN 1970 AND 2010 USING TIME FIXED EFFECTS. THE DEPENDENT VARIABLE IS THE LOG OF DEATHS. NUMBERS IN PARENTHESES ARE STANDARD ERRORS BASED ON THE HETEROSKEDASTICITY-REISTANT AND AUTOCORRELATION-RESISTANT COVARIANCE MATRIX. OTHER INDEPENDENT VARIABLES NOT REPORTED HERE ARE DUMMY VARIABLES FOR 18 WORLD REGIONS. SIGNIFICANCE CODES: 0.01 = *; 0.05 = **; 0.1 = *.**

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
Constant	−2.252***	−2.983***	−1.227	−3.100***	−1.253	−1.932**	−2.062**
	(0.774)	(0.761)	(0.838)	(0.788)	(0.841)	(0.868)	(0.876)
Log (#Disasters)	1.650***	1.562***	1.569***	1.574***	1.578***	1.535***	1.555***
	(0.119)	(0.118)	(0.118)	(0.120)	(0.120)	(0.118)	(0.119)
Pop Growth Rate	1.401***	1.220***	0.987**	1.076**	0.873*	1.037**	0.745
	(0.517)	(0.449)	(0.455)	(0.512)	(0.527)	(0.452)	(0.525)
Log (Lagged Pop)	0.252***	0.300***	0.266***	0.296***	0.262***	0.288***	0.278***
	(0.082)	(0.081)	(0.081)	(0.082)	(0.082)	(0.081)	(0.081)
Polity Score	−0.376***	−0.233*	−0.320**	−0.238*	−0.326**	−0.226*	−0.234*
	(0.132)	(0.134)	(0.130)	(0.134)	(0.131)	(0.133)	(0.134)
GDP per Capita (1000s)	−0.005			0.006	0.005		0.012
	(0.010)			(0.011)	(0.011)		(0.011)
Lagged IMR		0.010***		0.011***		0.008***	0.009***
		(0.003)		(0.003)		(0.003)	(0.003)
Female 20-39 Sec+ Edu			−1.472***		−1.523***	−1.076**	−1.173***
			(0.414)		(0.431)	(0.434)	(0.443)
Deviance	1135.210	1100.223	1104.476	1099.509	1104.081	1087.360	1084.830
AIC	2010.264	1993.109	1995.223	1994.753	1997.027	1988.664	1989.388
BIC	2130.839	2113.685	2115.799	2119.635	2121.909	2113.546	2118.576
N	548	548	548	548	548	548	548

These results support earlier findings that human development, in particular its education dimension, is positively associated with reduced disaster vulnerability at the national level. However, although quite correlated, the three dimensions of human development turn out to be of very different relative importance. GDP per capita turns out to be insignificant in all models while infant mortality and female education turn out to be highly significant in all models with the expected signs. Higher infant mortality, as an indicator of a worse public health system, is associated with relatively more disaster fatalities, while higher levels of female education are shown to be a dominant determinant of reducing disaster vulnerability.

As the main goal of the second part of the paper is to translate these results into predictions of future disaster vulnerability according to the SSPs, the concern is less with multicollinearity than with insignificant variables. Multicollinearity inflates standard errors making a possibly significant variable appear to be insignificant. Insignificant regressors in the original model, however, would increase prediction uncertainty. I therefore exclude the insignificant income dimension of human development and instead use Model 6 in Table 1, following the suggestion by the model selection criteria. All we need then is what has been called "the human core of the SSPs" (KC and Lutz 2014). This is what the next section will describe.

The SSP Scenario Framework

As discussed by Arnell et al. (2011), the SSPs were designed to include both a qualitative narrative component and a quantitative one describing the development of certain socioeconomic drivers of climate change numerically. This is supposed to represent a major upgrade of the IPCC's SRES emissions scenarios which have been very detailed on its assumptions with regard to energy use, technological development and implied emissions levels while being less explicit about demographic dynamics, including population only as a scaling variable and without any further disaggregation. In contrary to that, the SSPs are based on detailed population projections by age, sex, and level of education produced by the Wittgenstein Centre for Demography and Global Human Capital in Vienna (Eds.: Wolfgang Lutz, Bill Butz, Samir KC Forthcoming). While the five different SSPs presented in this paper cannot claim to depict the multitude of different futures, they nevertheless span a broad range of possible scenarios within the challenges to mitigation and adaptation space as described by O'Neill et al. (2013).

In the probably most optimistic scenario, SSP1, where the challenges both in terms of mitigation as well as adaptation are assumed to be small, the world makes very good progress toward sustainability. This is achieved by a high rate of technological progress and subsequent cooperation between the development leaders and followers. As a consequence, income levels rise steadily, poverty alleviation proceeds and global inequality is reduced. On the demographic side, SSP1 corresponds to a rapid demographic transition driven by rapid expansion in education systems. Low levels of fertility in today's high fertility countries eventually lead to a comparatively small overall population level.

SSP2 is referred to as the "middle of the road" scenario because it assumes intermediate challenges with respect to mitigation and adaptation to climate change. Compared to SSP1 nothing all too revolutionary is happening. Rather, we experience the continuation of current trends with regard to development, democratization or shifts in the global energy mix. Educational investments are still growing but not as fast as in SSP1. As a consequence, population growth does not decelerate by as much either, corresponding to medium assumptions both for fertility and mortality.

SSP3 describes a world of extreme fragmentation and polarization. While some global leaders pull ahead, large fractions of the world population, particularly in the global south, are left behind, leading to staggering inequality. The consequence is a stalled transition toward the knowledge society. Education does not increase nearly as much as in the previous scenarios, leading to high levels of fertility and unevenly distributed population growth. Also, since international cooperation is reduced to a minimum, migration between the newly developing regional blocks of countries also does not play a strong role in this scenarios population dynamics. Not surprisingly, challenges both to mitigation and adaptation appear to be insurmountable in this scenario.

SSP4 is different from SSP3 mainly because challenges to mitigation are reduced. Yet societies' future adaptive capacities are seen to be rather limited. This is both due to large within- and between-country inequality. On the one hand, it leads to large proportions of people who do not have the financial means for making a big contribution to global climate change as they are simply not rich enough to adopt consumerist Western lifestyles. On the other hand, climate change becomes a particularly strong threat for the vast proportion of disadvantaged people who are faced with big challenges for adaptation. Demographically this scenario corresponds to high inequality in the distribution of education. Subsequently, the country average of fertility remains very high in developing countries, whereas the fertility reversal in the rich OECD countries is cancelled because the social transformations facilitating it do not reach far enough.

Finally, SSP5 corresponds to conventional development – the idea that "more of the same", meaning unrestricted economic growth, is going to solve all economic and social problems alike. The environmental consequences of this emphasis on growth do of course lead to large mitigation challenges, while the adaptation challenges are rather small as a consequence of robust economic growth. Education is assumed to be high throughout the world; however the picture looks more complicated with regard to fertility. While fertility is comparatively high in today's richer and low fertility countries, the combination of work and family becomes increasingly more difficult everywhere else in the world. The overall effect on world population is mixed.

Figure 1. Total population in five major world regions according to Shared Socioeconomic Pathways (SSPs), 2010 - 2100.

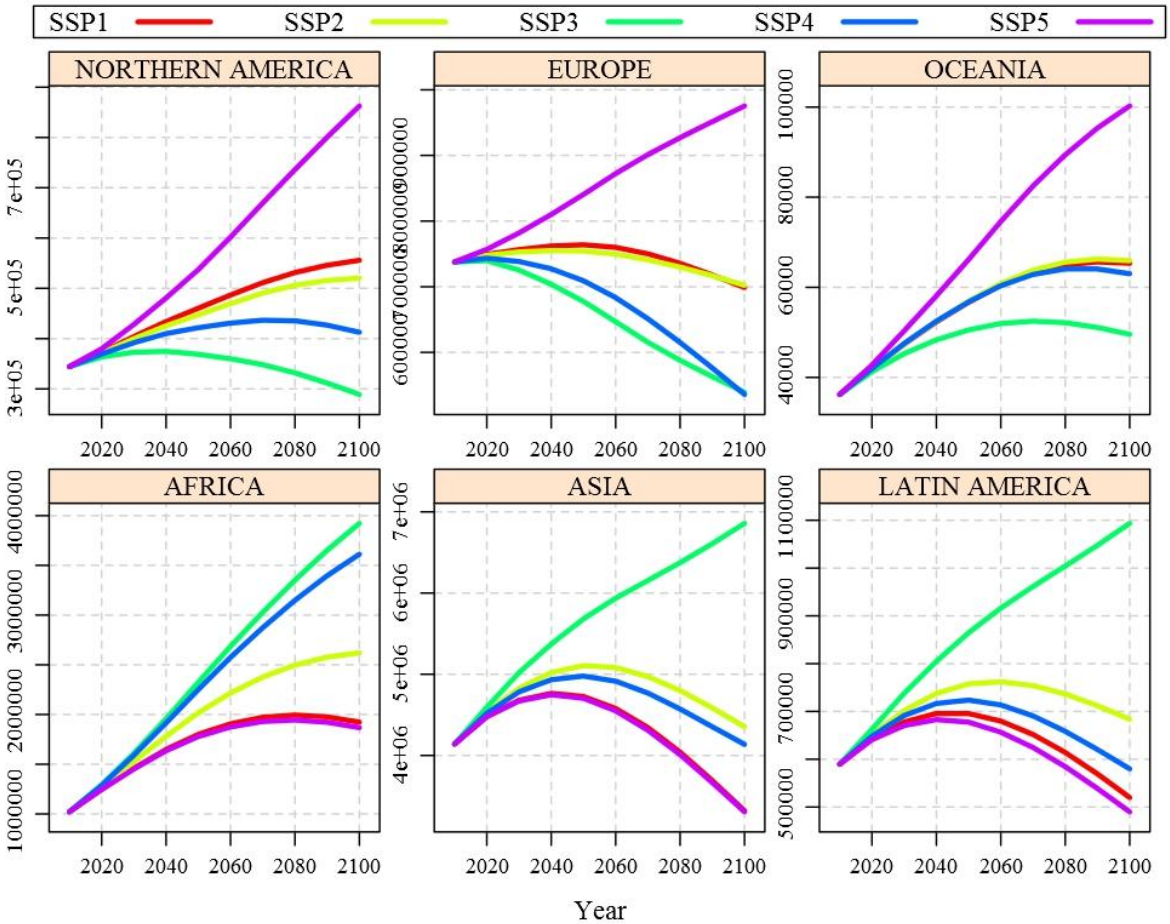


Figure 1 shows the specific demographic implications of SSP1 to SSP5 in terms of total population. Putting all regions on the same scale would show big differences between the scenarios only for Africa and Asia. But although future world population growth will be driven primarily by these two regions, the SSPs also correspond to very different pathways for the smaller regions. Note that all three developed regions in the top part of the figure in SSP5 would experience a reversal of the declining trends in their fertility, while the distorted work-life balance throughout the rest of the world would drive fertility down. As a consequence, population would increase particularly in the more affluent parts of the world thus leading to higher mitigation challenges for the planet as a whole.

Figure 2. Population by age, sex, and educational attainment according to Shared Socioeconomic Pathways (SSPs), Africa, 2100.

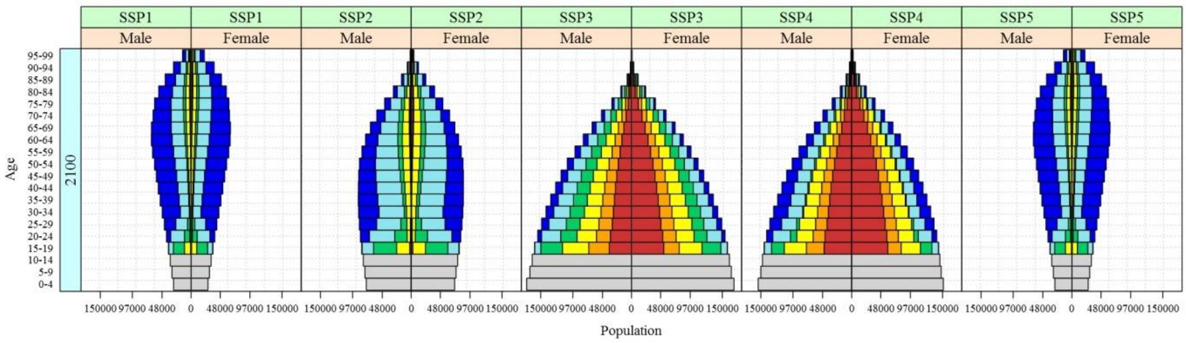
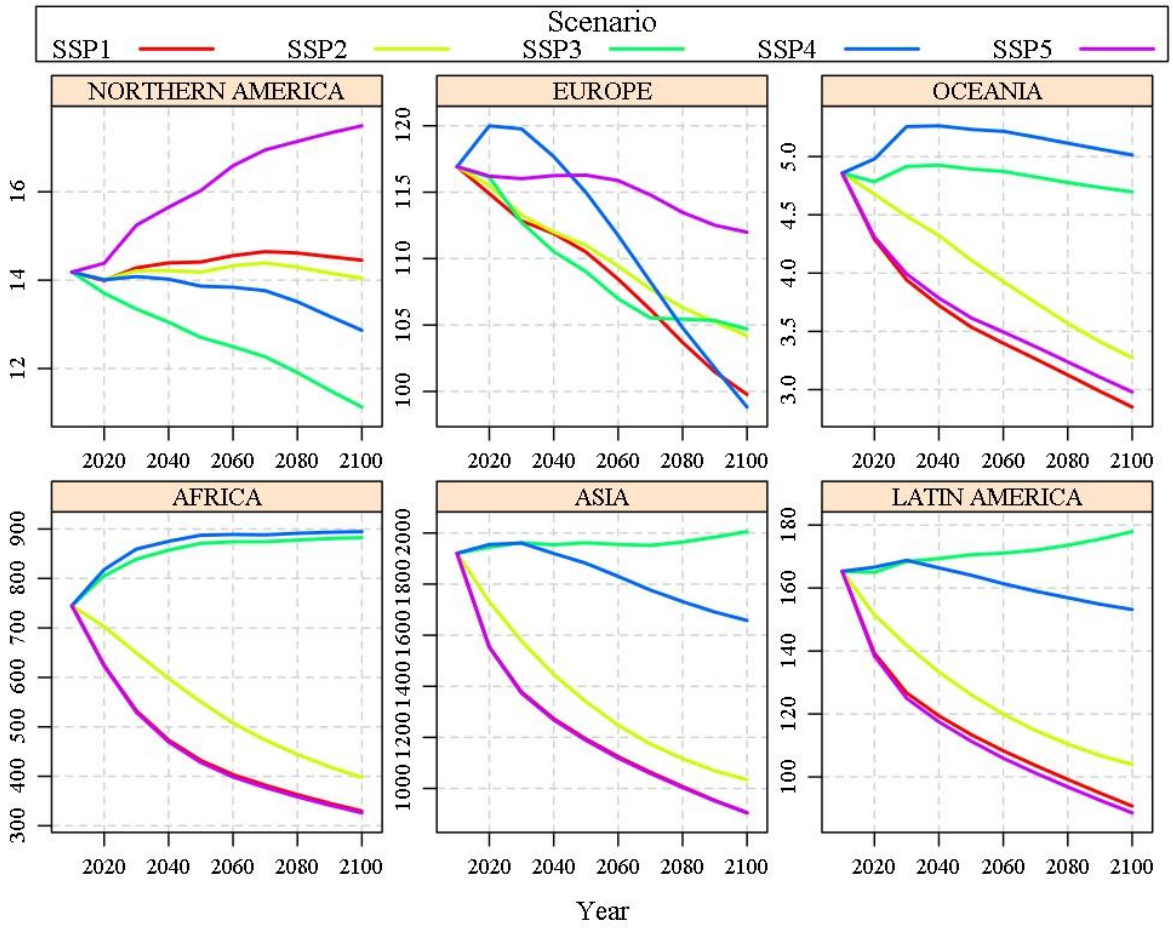


Figure 2 shows what the SSPs mean for the population of Africa in terms of its future age, sex, and education structure. Interestingly, both SSP1 and SSP5 lead to very high levels of education and low levels of overall population. Yet the development pathways leading to these results are very different; sustainability and low levels of emissions in SSP1, conventional GDP-focused development in SSP5. While it is beyond the scope of the present analysis, it would nevertheless be highly interesting to see what the differences in mitigation challenges between these two scenarios would mean in terms of climate hazard. Since nobody has translated the SSPs into world region specific future numbers of natural extreme events, though, in the following analysis I have to restrict myself to the study of the future adaptation challenges. It is clear however already at this point that due to the similarity of the demographic outcomes, these challenges are going to be fairly similar in these two scenarios.

The SSPs in Terms of Disaster Vulnerability

Finally, this section converts the findings by Striessnig et al. (2013) into decadal projections of future disaster vulnerability in five major world regions (results for smaller world regions are available on request) according to the SSP narratives. Since these narratives do not make equally explicit assumptions on the future number of natural disasters, political regimes or infant mortality as on the future of human capital, for simplicity I assume that these values will remain at their population-weighted regional averages for the 2000-2010 decade throughout the 21st century. The primary focus of this exercise is on the effects of population heterogeneity with regard to age, sex, and education.

Figure 3. Predicted number of decadal deaths (in 1000s) from natural extreme events assuming "Constant Hazard" for five world regions, 2010 - 2100.

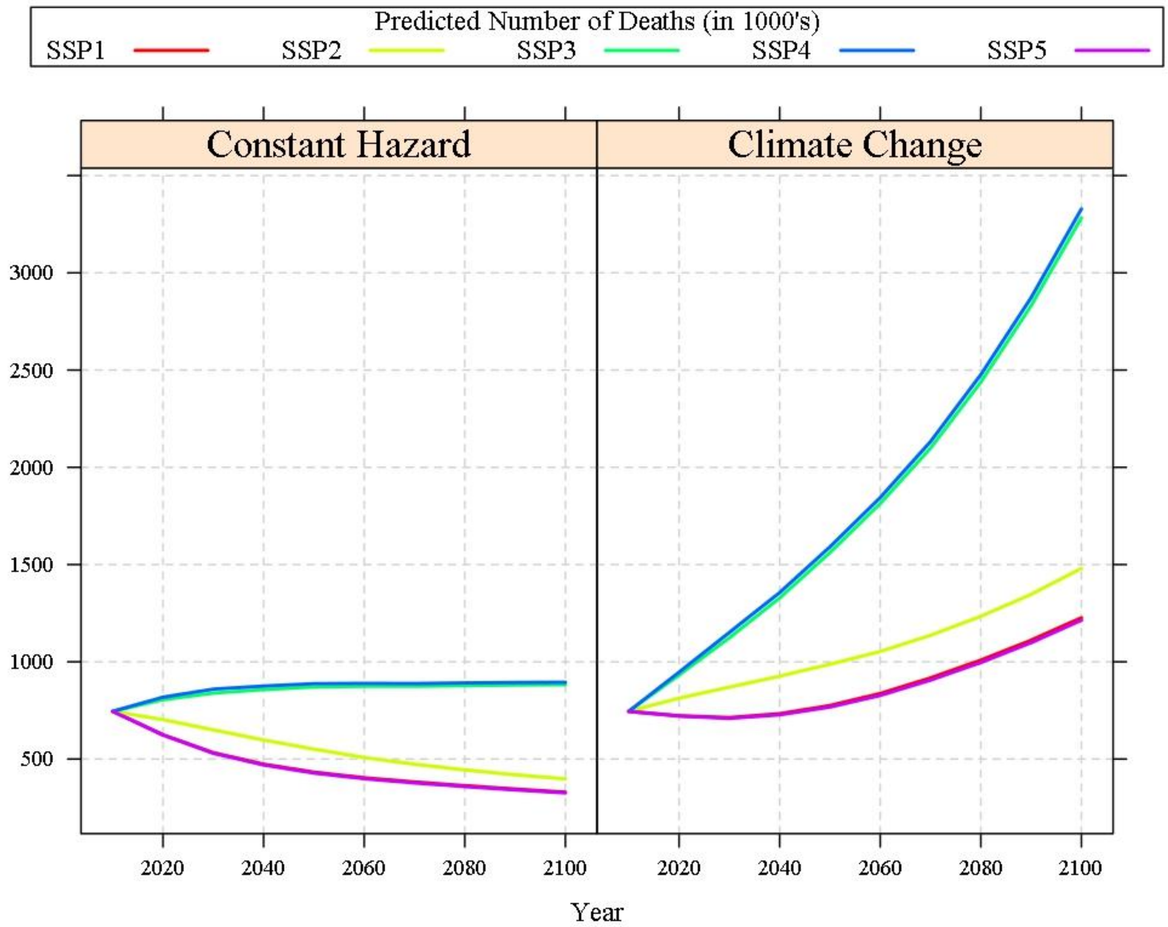


The results shown in **Error! Reference source not found.** for five major world regions do of course stem from highly stylized scenario calculations. Since different sub-regions will change from positive to negative population growth in different decades, the regional aggregates of decadal deaths are not simply monotonic. In addition to that, the trajectory depends on the trade-off between vulnerability-reducing increases in educational attainment and vulnerability-increasing population growth.

Since the general assumption behind the results shown in **Error! Reference source not found.** is that hazard will remain constant, we see a decrease in the predicted number of deaths in all scenarios except fragmentation (SSP3) and inequality (SSP4). What if, however, the future hazard does not remain constant but instead increases as a consequence of climate change? Since assessments of the future frequency of natural disasters around the world depend on a myriad of factors such as geography, type of disaster, or societies' capacities to prevent them from happening in the first place, to name just a few, the IPCC is careful in quantifying the effect of climate change on the number of natural extreme events. There seems to be a general consensus, though, on an upward trend in frequency of appearance with regard to almost any type of disaster as a consequence of sea level rise and a higher global mean temperature. (Intergovernmental Panel on Climate Change 2012).

The results presented in Figure 4 below, therefore, assume a 10 percent decadal increase in the frequency of natural extreme events. Many climate change researchers may think that this is still far too conservative for the more distant future when the negative effects of climate change may accelerate. In such a case, the calculated effects contingent on the assumed future hazard levels will be proportionately higher than in the examples shown below.

Figure 4. Predicted number of decadal deaths (in 1000s) from natural extreme events assuming "Constant Hazard" (left) and "Climate Change" (right), Africa, 2010 - 2100.



In any case, even an increase of 10 percent per decade results in a dramatic rise in fatalities and highlights the potential for near term investments in education to reduce these risks. Much more context-specific analysis of differential vulnerabilities and the role of demographic factors including education is needed in order to arrive at robust country-specific forecasts and policy recommendations. In general, however, there can be no doubt that universal basic education of the entire population (including basic literacy and numeracy) is a key factor in enhancing the adaptive capacity and reducing the vulnerability of individuals, communities, and entire nations. Hence, when it comes to the choice of priorities for investments in adaptation, the currently favored engineering solutions should be critically compared to the long term benefits of investing in human capital formation and the general empowerment to flexibly and effectively react to partly still uncertain location specific climate change effects.

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