Chapter 4.5 Exploring regional coastal populations at risk of sea level rise using future socioeconomic pathways under high and low emission scenarios

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4.5 Exploring regional coastal populations at risk of sea level rise using future socioeconomic pathways under high and low emission scenarios

4.5.1 Summary and Key Messages

We estimate the risk of sea level rise (SLR) within a framework of hazard, exposure and vulnerability using internally consistent future development scenarios (or pathways) for 139 coastal countries over the time period 2010-2100. We combine socioeconomic and greenhouse gas concentration pathways into five future reference development pathways or scenarios: Shared Socioeconomic Pathway (SSP)1 (sustainable development) and SSP4 (inequality) with Representative [greenhouse gases and pollutants] Concentration Pathway (RCP) 4.5 to form low emission scenarios; and SSP2 (middle of the road), SSP3 (stalled development), and SSP5 (fossil fuel led development) with RCP8.5 to form high emission scenarios. The emission scenarios as elaborated by the Fifth Assessment Report of the IPCC provide regional estimates of sea level rise for the period 2010 to 2100, and which we use as hazard measures for estimating risk of sea level rise. The SSPs provide projections of human development metrics, including population, life expectancy at birth (health measure), mean years at school, females with tertiary education as a percentage of women of childbearing years (20-39 years) (education measures), and GDP in 2005 US$ PPP (income measure) at country scale over the same time period (2010 to 2100). We combine these human development measures into a Human Development Index (HDI) at country scale annually for the 90-year period. We take the difference between the theoretically highest level of human development and the projections called the Human Development Index Gap (i.e. 1.0-HDI) as a measure of vulnerability.

We estimate exposure to sea level rise in terms of total land area in three coastal zones defined by horizontal cumulative distances 10km, 30km and 50 km from shore, and each width intersecting with elevation data to 10 m, and greater than 10m elevations for the benchmark year 2100. The MESSAGE land use model is used to obtain total land values for each of the three coastal widths in 2100, under a high emission scenario and assume these to be the same for RCP4.5 (low emission scenario). We distribute the projected SSP populations in the three coastal widths using a reference distribution map of global population in 2100 that is based on a UN population model with medium growth variant for calibration. Both land area and population values are used as exposure metrics in calculating an SLR Risk Index.

The estimation of risk to future sea level rise is weighted equally by the hazard, exposure and vulnerability metrics above. The SLR Risk Index is calculated as the geometric mean of: (a) the projected sea level rise estimates in either RCP4.5 or RCP8.5 for the reference year 2100 (hazard measures); exposed land area and population within vulnerable zones of up to 10 m elevation at cumulative distances of 10, 30 and 50 km distance from shore (exposure metrics); and the projected Human Development Index Gaps (i.e. 1- HDI) (vulnerability measures). We report risk estimates to sea level rise within country coastal zones 50 km wide up to 10 m in elevation and compare their magnitudes across the five reference development pathways.

The analysis in this study highlights several key messages:

1. Among the three equally weighted and uncorrelated (i.e. less than correlation coefficient of 50%) measures of hazard, exposure and vulnerability used in assessing SLR risk, vulnerability correlates the most with resulting SLR risk at 79 – 85 per cent. This is evident across all five future development pathways.
2. For a country, hazard measures for low emission scenarios differ from those for high emission futures. Averaging the ranks of countries for both high and low scenarios, the list of countries facing the highest levels of SLR are: the USA, Canada, Russia, South Africa and Mozambique (tied for 4th place), Japan, Australia and New Zealand (tied for 7th place), Madagascar and Mauritius, in order of decreasing rank.

3. Exposure differs across SSP scenarios because of population differences, even with total land area in the 50km coast remaining the same under both low and high emission pathways. Averaging their exposure ranks across the five future scenarios, the countries with highest exposure in decreasing order are: the USA, Indonesia, China, India, Brazil, Viet Nam, Nigeria, Bangladesh, Egypt and Australia.
4. Using HDI Gap as vulnerability metric, the most vulnerable countries, based on their average vulnerability ranks across five future scenarios in decreasing order are: Somalia, Mozambique, Sierra Leone, Liberia, Madagascar, Guinea-Bissau, Solomon Islands, Eritrea, Papua New Guinea and Benin.
5. The ten countries most threatened by SLR indicated by the SLR Risk Index, on average and across the five reference projection pathways (in decreasing order) are: Somalia, Mozambique, Madagascar, Angola, Liberia, Sierra Leone, Papua New Guinea, Senegal, Guinea-Bissau and Mauritania. Seven of these coastal states are identified among the most vulnerable.
6. Despite an overall projected trend of increasing levels of human development among all countries and regions across all reference futures, there are scenarios, for example high emission SSP3 (stalled development) where gender-sensitive education indicators are projected to decrease, and which contribute to increasing vulnerability and risk by 2100. Even if these do not decrease, such as when the proportions of females that finish tertiary education are increasing but not fast enough, vulnerability is projected to remain significantly high for these countries.
7. Societal choices reflected in the five reference development pathways underpin hazard, exposure and vulnerability metrics of risk to SLR. They also indicate strategic ways to mitigate risk. Reducing emissions and population growth are critical, but reducing vulnerability by nurturing human development, appears the most prudent with long-term generational impacts. The reduction of risk through improved education, health and income are key to sustaining households and societies. However, human development must be pursued within a sustainability framework where clear limits in greenhouse gas emissions are capped for both developing and developed economies, despite uncertainties in projecting sea level rise, and in predicting low probability but high impact SLR scenarios.

4.5.2 Main Findings, Discussion and Conclusion

Wellbeing and future scenarios of sea level change

Sea level rise (SLR) is a cumulative response of the oceans and the cryosphere to atmospheric warming caused by the mounting concentration of greenhouse gases emitted during fossil fuel burning and from land-use changes such as deforestation. In the fifth assessment (AR5) of the Intergovernmental Panel for Climate Change (IPCC), Church et al. (2013) reported that ocean warming and glacial and ice sheet melting explain 75 per cent of the observed increase in global mean SLR from the early 1970s to 2010. Based on process-based models used in this assessment, the global mean SLR in the future Representative Concentration Pathway (RCP)8.5 reference scenario (warmest scenario) is projected, with medium likelihood, to reach a median value of 74 cm with a range of 0.52 to 0.98 m (5 to 95 per cent range) by 2100 (Table 13.5 in Church et al. 2013); for RCP4.5, the projected median value by 2100 is 53 cm with a range of 0.36 to 0.71 m (5 to 95 per cent range).

The report further indicates that toward the end of the current century, it is very likely that over 95 per cent of the global ocean will experience sea level rise, with the remaining areas located near glaciers and ice sheets very likely to experience sea level fall. Church et al. (2013) estimated that about 70 per cent of coastal areas are projected to experience relative sea level change within 20 per cent of the global mean. The sea level estimates used in the current study are obtained from AR5, for RCP4.5 (low emission) and RCP8.5 (high emission) scenarios.

The AR5 report on SLR (Church et al 2013) has triggered critical reviews of the models used to generate current and future SLR estimates, the confidence intervals around these estimates, and inability of the IPCC to evaluate ice sheet instabilities, which may underpin potentially catastrophic and rapid increases in SLR. Hinkel et al. (2015) state that low probability upper-bound scenarios are needed for risk management, and that the AR5 SLR assessment fails to provide these. While true, this criticism reflects the state of the science, and Church et al 2013, point out that what was known at the time of the fifth assessment was deemed insufficient to provide scientific guidance on upper bound SLR contributions from melting ice sheets. On the issue of the wide disparities between projections provided by semi-empirical models with those derived from processed-based models which IPCC prefers, Kopp et al (2016) very recently estimated GSL over the last 3000 years using Bayesian semi-empirical modelling, and provided 2100 projections that overlap those of Church et al 2013. Mengel et al (2016a) showed component-based contributions to 2100 GSL using Bayesian semi-empirical modelling as well, and the 5-95% ranges at component-scale likewise overlap with those of Church et al (2013). However, it is important to note that these more current semi-empirical models, like the AAR5 process-based models, are still unable to incorporate instabilities in ice sheet dynamics because of lack of prior analogues for semi-empirical models and inadequate representation of ice sheet instability in process-based models.

Because of many unknowns and large uncertainties in current knowledge about ice sheet melt and its contribution to sea level rise, Church et al. (2013) did not provide an upper bound of sea level rise by 2100. Jevrejeva et al. (2014) published a low probability upper limit of 1.8 m for sea level rise by 2100, using expert elicitation from ice sheet scientists to fill in the significant observation gaps. Though not definitive, providing an estimate of upper bound sea level rise, imperfect though it may be, fills a serious need among risk-averse coastal planners (Hinkel et al. 2015, Jevrejeva et al. 2014). Kopp et al. (2014) provides a consistent set of local sea level rise estimates, including the contribution of ice sheet melting, around a global network of tide gauges with probability distributions as an initial attempt to provide information useful for local coastal planning.

A number of studies have turned to examine past warm periods when ice sheets lost considerable mass resulting in significant sea level rises. Kopp et al (2009) showed that peak global sea level during the last interglacial stage (about 125 thousand years ago), a partial analogue of a 1-2°C warming scenario, very likely (95% probability) exceeded 6.6 m higher than today, and likely (67% probability) to have reached above 8.0 m, but was unlikely (33% probability) to have exceeded 9.4 m, with millennial SLR rates very likely exceeding 5.6 m per thousand years and unlikely exceeding 9.2 m per thousand years. Although these earlier periods might not be analogues of a future earth that is greatly anthropogenically altered relative to greenhouse emissions, pollutants, and other factors, the high uncertainty and potentially catastrophic consequences of significant ice-sheet melting leading to multi-metre sea level rise over thousand years in the future make the science and politics of sea level rise as contentious as ever. Very recently, Mengel et al (2016b), using simulations of warm water intrusion into the cavity of West Antarctica's Filchner-Ronne ice shelf over the next two centuries, showed that ice melt is determined by the strength of ocean warming, which when weak may be dominated by local ice instabilities. These findings suggest that scientists and citizens alike need to be open to low probability but high impact futures as potential scenarios of sea level change.

The uncertainty and contentiousness of SLR impacts become magnified and made more complex when linked to examining how coastal societies may respond to sea level rise in the future. The exposure of coastlines and human populations and infrastructure to coastal erosion, flooding, storm surges, saltwater intrusion to near shore aquifers, and gradual submergence of wetlands and coastal ecosystems threaten lives, livelihoods, properties and economies. Talaue-McManus and Estevanez (2016) estimate that about 40 per cent of the global population, or 2.7 thousand million people, lived within the 100 km coastal zone, which account for 22 per cent of the global land area, in 2010. Compared to inland areas, the global coastal zone is crowded, with nearly 60 per cent of coastal inhabitants living in urban centres. The increase in economic activity and wealth in the coastal zone accounts in full for the increases in losses in areas susceptible to land-falling tropical cyclones in the past six decades (Weinkle et al. 2012; Mendelsohn et al. 2012). However, there is also unevenness in the distribution of wealth so that, on average, one in five coastal dwellers worldwide is considered poor on the basis of national poverty standards (Talaue-McManus and Estevanez 2016). Given these baseline conditions of today's global coast, one may ask how these will change in the years leading to 2100, the reference year for projections of a warming planet and a rising sea. How may the present day sources of vulnerabilities persist, and if so, be mitigated, to enhance the capacity of coastal societies to cope with climate change, including sea level rise?

Previous studies have examined impacts of sea level rise. Nicholls et al (1999) and Nicholls (2004) examined flood risk and wetland losses under various SLR and socioeconomic scenarios. Dasgupta et al. (2011) analysed the exposure of 84 developing countries to modelled storm surges and sea level rise of 1 m using six indicators of exposure (exposed land area, population, economic activity, urban extent, agricultural extent and wetlands), but were limited to using current conditions of land use, population and GDP. Hinkel et al (2014) analyzed coastal inundation damage and adaptation costs at global scale under 21st century sea level rise. Neumann et al. (2015) examined coastal population growth and exposure to sea level rise and coastal flooding for 2000 (baseline), 2030 and 2060 using scenario guidelines developed by the UK's Foresight Project on Migration and Global Environmental Change. The current study focuses on the RCP scenarios that influence land use and sea level rise changes for the period 2010 to 2100; and the SSP scenarios that prescribe the trends in population and well-being among coastal states and their resulting vulnerability to sea level rise over the same period.

The study aims to provide scenarios of spatially distributed coastal populations and land area in the coastal zone to 2100. To make these estimates computationally feasible, we chose two physical pathways (RCP4.5 and RCP8.5) and five socioeconomic pathways, combined to form internally consistent development scenarios: SSP1 and SSP4 combined with RCP4.5 to form low emission development scenarios; and SSP2, SSP3 and SSP5 combined with RCP8.5 to form high emission development scenarios.

The high emission pathway chosen for this exploratory study is RCP8.5, with radiative forcing reaching >8.5 W/m^2 by 2100, then increasing further. This pathway features increasing greenhouse gas emissions which lead to high concentrations of greenhouse gases (1 370 ppm CO_2 equivalent) with a projected median temperature increase of 4.9°C above the pre-industrial level by 2100 (Riahi et al. 2007, Riahi et al. 2011, Rogelj et al. 2012).

The low emission pathway is RCP4.5, with radiative forcing reaching 4.5 W/m^2 by 2100, stabilizing at this level after 2100 without overshoot. In this pathway, the median temperature increase reaches 2.4°C above pre-industrial level, and with an equivalent CO_2 emission of 650 ppm in 2100 (Thomson et al. 2011, Rogelj et al. 2012).

Both radiative forcing pathways set the sea level rise values used in this study following the IPCC Fifth Assessment of sea level change (Church et al. 2013). For total land areas, we processed the RCP8.5 land-use model data layer (Hurtt et al. 2006) to obtain the total land area at elevations ≤10 and higher, co-located in ≤10 km, ≤30km and ≤50 km coastal widths. We assumed that the total coastal land areas in 2100 under RCP4.5 to be the same as those in RCP8.5.

A second objective of this study is to explore wellbeing and vulnerability to sea level rise using modelled time series of metrics from 2010 to 2100. These models follow the reference characteristics of the Shared Socioeconomic Pathways developed by the IPCC Working Group II (O'Neill et al. 2014; O'Neill et al. 2015). The RCP pathways are combined with appropriate SSP development pathways to make coherent physical-socioeconomic future narratives as a context for exploring risk to climate-related phenomena including sea level rise. For this study, low emission-based scenarios SSP1-RCP4.5 and SSP4-RCP4.5 and high emission-based scenarios SSP2-RCP8.5, SSP3-RCP8.5 and SSP5-RCP8.5, provide the integrated internally coherent reference contexts for the analysis of hazard, exposure, and vulnerability to evaluate overall risk.

Main Findings, Discussion and Conclusions

Sea level rise to 2100 under RCP4.5 and RCP8.5. Figure 4-43 shows the changes in sea level in 2010 and 2100 under RCP4.5 and RCP8.5. Table 4-2 provides the ranges of country-scale maximum SLR projections aggregated by regions for both low and high emission scenarios.

Under the low emission scenario (RCP4.5), the United States and Canada have the highest projected SLR by 2100 at 0.725 m and 0.694 m, respectively. The Caribbean (0.628 m), Eastern Europe (Russia and Poland only) (0.624 m), Eastern Africa (0.617 m), Southern Africa (0.609 m), Eastern Asia (0.604 m) and Oceania (0.601 m) have the highest projected SLR at regional scale.

Under the high emission scenario (RCP8.5), the United States in Northern America and Russia in Eastern Europe are projected to experience the highest SLR at over 0.9 m. The tropical coastal regions of Africa, Asia, Oceania, Central America and the Caribbean are projected to have high SLR maxima at or higher than 0.8 m. About 131 countries or 94 per cent of 139 coastal states examined face projected SLR of 0.6 m and higher by 2100. Under a low emission scenario (RCP 4.5), 128 countries of 139 assessed are projected to experience SLR levels below 0.6 m by 2100.

The SLR estimates above require further fine-scale calibration. At the coast, what is critical is 'total' relative sea level change which is the net sum of (1) sum of global mean rise and the regional variability; (2) static factors (e.g. solid earth responses such as land uplift with melting of overlying ice and icequakes triggered by fracturing ice) causing regional sea level change, and (3) local vertical land movement (Cazenave and Le Cozannet 2013). While global models can help elucidate global mean sea level change and regional variability, these require complementary analysis of additional sources of relative sea level rise and an assembly of fine-scale data and analysis by national communities of scientists to resolve static factors and local vertical land motion so that the estimated magnitude of SLR that would impact coastal communities may be further constrained. The RCP projections above are therefore coarse estimates that finer-scale studies need to fine-tune for these to become relevant to the needs of local coastal planning.

Equally important to stress is the uncertainty introduced by rapid ice-sheet melting dynamics which Church et al. (2013) could not evaluate during the IPCC AR5 because of inadequate knowledge at the time. The low probability upper bound of global mean sea level rise of 1.8 m as proposed by Jevrejeva et al. (2014), together with other estimates from other models, such as semi-empirical approaches (Vermeer and Rahmstorf 2009), also need to be systematically examined and regionalized. Kopp et al. (2014) provide local SLR estimates with probability distributions for a global tide gauge network, incorporating the influences of ice-sheet dynamics and groundwater extraction, among others. For this current study focusing on global comparisons of local SLR, the use of what may appear as conservative estimates of regional sea level rise by Church et al. (2013) are considered first approximations and work in progress.

Figure 4.43. Hazard metrics. RCP 4.5 total ensemble mean sea surface height for (a) 2010 and (b) 2100, and RCP 8.5 total ensemble mean sea surface height for (c) 2010 and (d) 2100. Maps were plotted using the University of Hamburg Integrated Climate Data Center Live Access Server at http://www.icdc.zmaw.de/las/getUI.do. Note that the color legend for each map differs in values as the range of minimum and maximum sea level rise estimates increases with time.

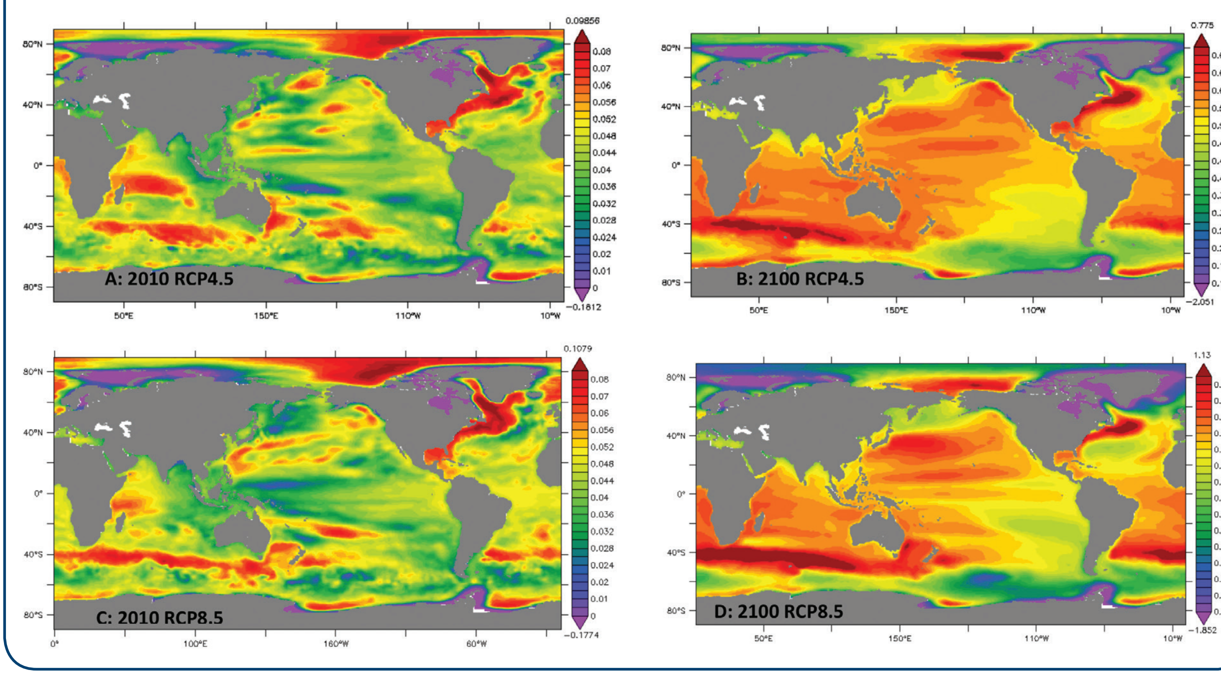


Table 4.2 Hazard metrics using ranges of country-scale maximum sea level rise derived from RCP8.5 projections of Church et al. (2013) in the IPCC AR5.

Region	RCP 8.5		RCP4.5	
	Low Maximum SLR (Country-scale, m)	High Maximum SLR (Country-scale, m)	Low Maximum SLR (Country-scale, m)	High Maximum SLR (Country-scale, m)
Northern Africa	0.675	0.743	0.463	0.485
Western Africa	0.750	0.836	0.524	0.562
Middle Africa	0.785	0.836	0.552	0.595
Southern Africa	0.828	0.851	0.578	0.609
Eastern Africa	0.702	0.845	0.465	0.617
Western Asia	0.402	0.778	0.380	0.559
Southern Asia	0.669	0.801	0.392	0.572
Southeastern Asia	0.716	0.814	0.528	0.596
Eastern Asia	0.750	0.830	0.523	0.604
Oceania	0.784	0.861	0.580	0.601
Northern America	0.890	0.960	0.694	0.725
Central America	0.734	0.800	0.506	0.592
Southern America	0.691	0.784	0.475	0.580
Caribbean	0.732	0.805	0.550	0.628
Northern Europe	0.293	0.742	0.070	0.508
Western Europe	0.677	0.759	0.485	0.539
Southern Europe	0.587	0.710	0.393	0.556
Eastern Europe*	0.625	0.904	0.365	0.624

**No sea level rise data for Bulgaria, Georgia, Romania and Ukraine, around the Black Sea.*

Legend:		Countries RCP8.5	Countries RCP4.5
SLR ≥ 0.900	Very high SLR	2	0
0.800 ≤ SLR < 0.900	High SLR	27	0
0.700 ≤ SLR < 0.800	Medium SLR	70	1
0.600 ≤ SLR < 0.700	Low SLR	32	10
SLR<0.600	Very low SLR	8	128
	No SLR data	4	4

Total land areas and RCP8.5 land uses in the coastal zone in 2100. For both land use area and population distribution in the coastal zone, we define those co-located within the ≤10 m elevation and within the ≤50 km from shore to be the most susceptible to the adverse impacts of SLR and associated phenomena such as coastal storm surges and episodic coastal inundation. The chosen elevation ranges are dictated by the overall vertical resolution of the ACE2 DEM of about 5 m, which varies with location and the extent to which altimeter and Shuttle Radar Tomography Mission (SRTM) readings, which provided digital elevation data at near global scale, have been blended. The estimated land and population distribution in coastal space, defined by intersecting elevation and distance from shore for the 50 km global coastal width, is the first global data set of its kind. Other global data sets provide distribution estimates by elevation independently of those by distance from shore, as in the case of CIESIN population data layers (2013). The use of three-dimensional spatial distribution of population and land use is required for modelling physical and socioeconomic impacts of coastal processes such as flooding. At a global scale, the GIS implementation is computer-intensive and at best coarse. However, the approach is invaluable for comparing magnitudes of potentially affected populations and areas along the global coast notwithstanding the variable widths of floodplains.

For the current study, we use total land areas in the 10 m elevation intersecting the 50 km coast as land exposure metrics. The computer-intensive land use analysis was done only for RCP8.5, results for which are presented in Annex Table 1. Comparison of land use between low and high emission scenarios will be done when analysis of RCP4.5 data is completed. Values for total area include inland waters, ice, and desert areas in addition to the three evaluated land-use areas, as applicable. For RCP8.5 agricultural land use in 2100, areas within the coastal zone (10 m elevation X 50 km from shore) are widest in Southeastern Asia (99 296 km^2), Southern America (74 538 km^2), Oceania (mostly Australia, 62 447 km^2), Central America (57 268 km^2), Southern Asia (46 534 km^2) and Eastern Africa (33 841 km^2). These areas may be widened as locally and regionally appropriate, depending on the widths of the coastal floodplains. Approximate areas for coastal widths ≤ 10 km and ≤ 30 km from shore and up to 10 m elevation are provided in Annex Table 1.

Urban land use within the ≤ 10m elevation - 50 km coastal space is highest in Eastern Asia (10 963 km^2), Southeast Asia (7 988 km^2), Northern America (4 993 km^2), Southern Asia (3 894 km^2), Western Africa (3 878 km^2), and Western Europe (3 784 km^2).

Primary and secondary vegetated areas in the coastal zone are most extensive in Southeast Asia (162 827 km^2), Northern America (148 946 km^2), Eastern Europe (79 697 km^2), Southern America (79 181 km^2), Oceania (51 181 km^2), Central America (45 585 km^2) and Northern Europe (44 370 km^2).

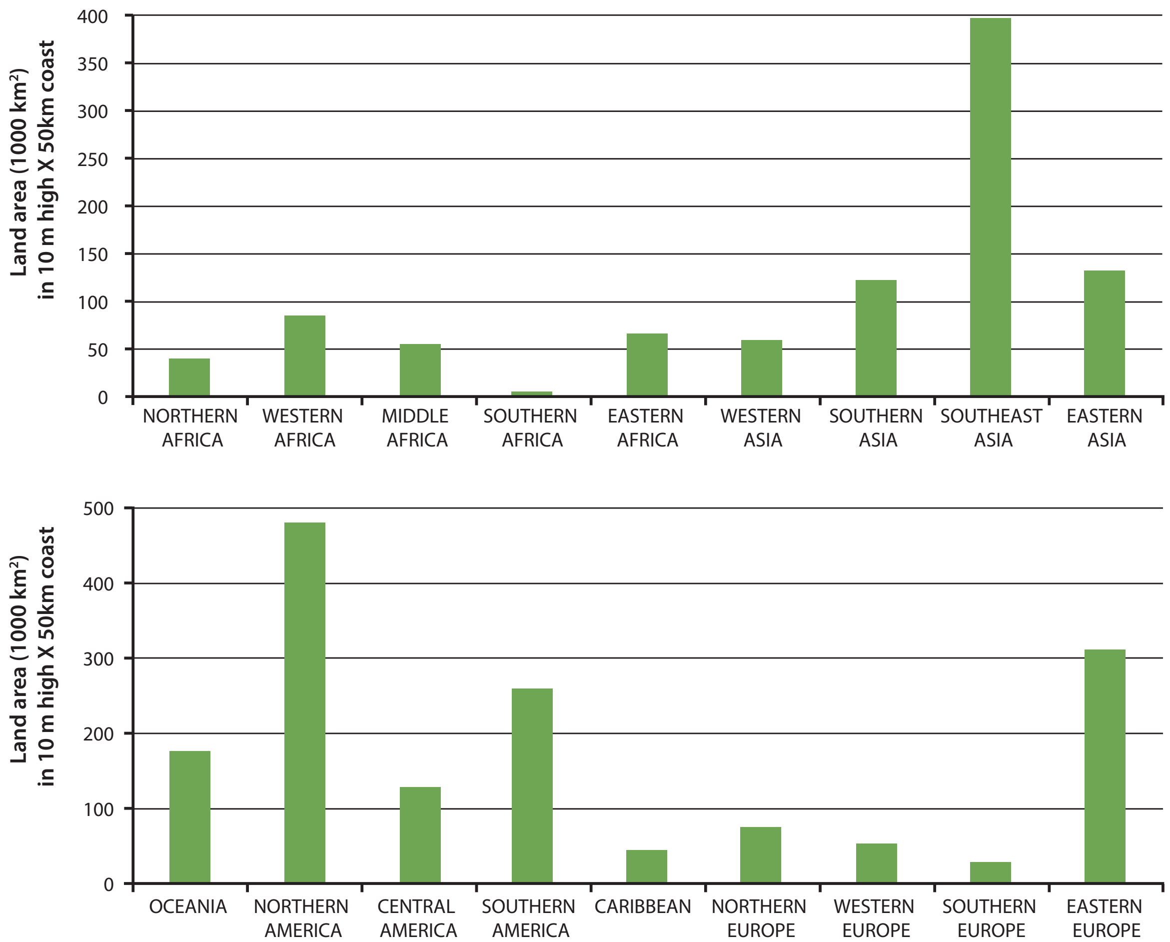
Figure 4.44 shows coastal land areas in the 10 m elevation co-located in the 50 km coast for 139 countries aggregated into 18 regions, and which are the same for both low and high emission reference futures in 2100. Northern America (480 049 km^2), Southeastern Asia (397 495 km^2), Eastern Europe (330 654 km^2), and Southern America (260 002 km^2) have the highest land exposure (in decreasing order).

SSP populations in the coastal zone in 2100. In analysing population trends to 2100, the modelled data for SSP 1-5 narratives are used. Figure 4-45 shows the regional populations in 2100 totals by SSP pathways, grouped into low emission (SSP1 and SSP4) and high emission (SSP2, SSP3, and SSP5) scenarios. Population increase is most pronounced for SSP3 (Regional Rivalry) where population growth rates and fertility rates are high for both high and low fertility countries, and low for rich OECD countries (O'Neill et al. 2015). Major population centres in Southern Asia (22 per cent), Southeastern Asia (15 per cent), Western Africa (11 per cent), Eastern Asia (8 per cent) and Northern Africa (8 per cent) account for 64 per cent of the most susceptible coastal inhabitants.

SSP2 (Middle of the Road) and SSP4 (Inequality) follow similar patterns. SSP2 features moderate growth rates. SSP4 exhibits high population growth and high fertility rates for high and low fertility countries, and low population growth and low fertility rates for rich OECD countries. SSP5 (Fossil-fuel led development) has the second to lowest population growth rates with low growth and fertility rates for both high and low fertility countries, and low growth but high fertility for rich OECD nations. SSP1 (Sustainable World) has the lowest population growth where fertility is maintained low for both High and Low Fertility countries, and kept at medium for rich OECD states.

Table 2 shows the spatial distribution of the coastal population within 10 m elevation by 10, 30 and 50 km coastal zone by SSP. The spatially explicit distributions in co-located elevation and width coastal spaces allow for comparisons, and may be customized to actual widths of floodplains in refining exposure at finer scales. Because the SSP country populations are time-series values and not geo-referenced data sets, the populations are distributed spatially following national ratios obtained when the CIESIN (2013) population data layer is wrapped on the ACE2 DEM. The ratios of populations by distance from shore are therefore constants across SSPs. There is no reason to believe that population distribution will follow a single pattern across reference SSPs. In the absence of geo-referenced population data layers for the SSPs, we use the resulting populations in the 10 m high X 50 km distance from shore as coarse and proxy measures of exposure. Highly exposed populations, or those within the 10m high X 10 km distance from the coast, make up 55 per cent of the total SSP global population within the 50 km coastal zone. Those projected to be within 10 m high X 30 km distance account for 85 per cent of the projected SSP global population in the 50 km wide coastal zone. Under a low emission scenario, exposed population in the 10 m X 50 km coast in 2100 for 139 countries varies from 574 million for SSP1 to 645 million for SSP4. Under a high emission scenario, exposed population is least in SSP5 at 631 million, increasing to 697 million in SSP2 and is largest at 937 million in SSP3.

Figure 4.44. Exposure metrics. Land area up to 10 m elevation co-located within 50 km distance from shore in 2100 for 139 SSP countries. Land areas are assumed to be the same across the five reference futures. Northern America, Southeastern Asia, Eastern Europe and Southern America, have the highest land exposure, in decreasing order.



Global Trends in well-being and vulnerability for 2010-2100. In this section, we explore the trends in well-being metrics, some of which we use to construct Human Development Indices (HDI) over the same period as a way of comparing capacities of countries and regions to deal with climate change including sea level rise.

The influence of individual metrics at the global scale are explored in this section (Figure 4): life expectancy at birth (E0), mean years at school, the proportion of females of childbearing ages (20-39 years) with tertiary education, and per-capita gross domestic product over the next 90 years, across the five reference socioeconomic pathways (SSP1-5). Figures 4-46B to 4-46F show the global trends. Life expectancy at birth for SSPs 1 and 5 follow almost the same pattern, with very long life expectancies resulting from high investments in health (Annex Table 2) (Figure 4-46B). By

Figure 4.45. Exposure metrics. Regional population under low emission SSPs (SSP1 and SSP4) and high emission SSPs (SSP2, SSP3 and SSP5) within the 10 m elevation intersecting the 50 km coast in 2100.

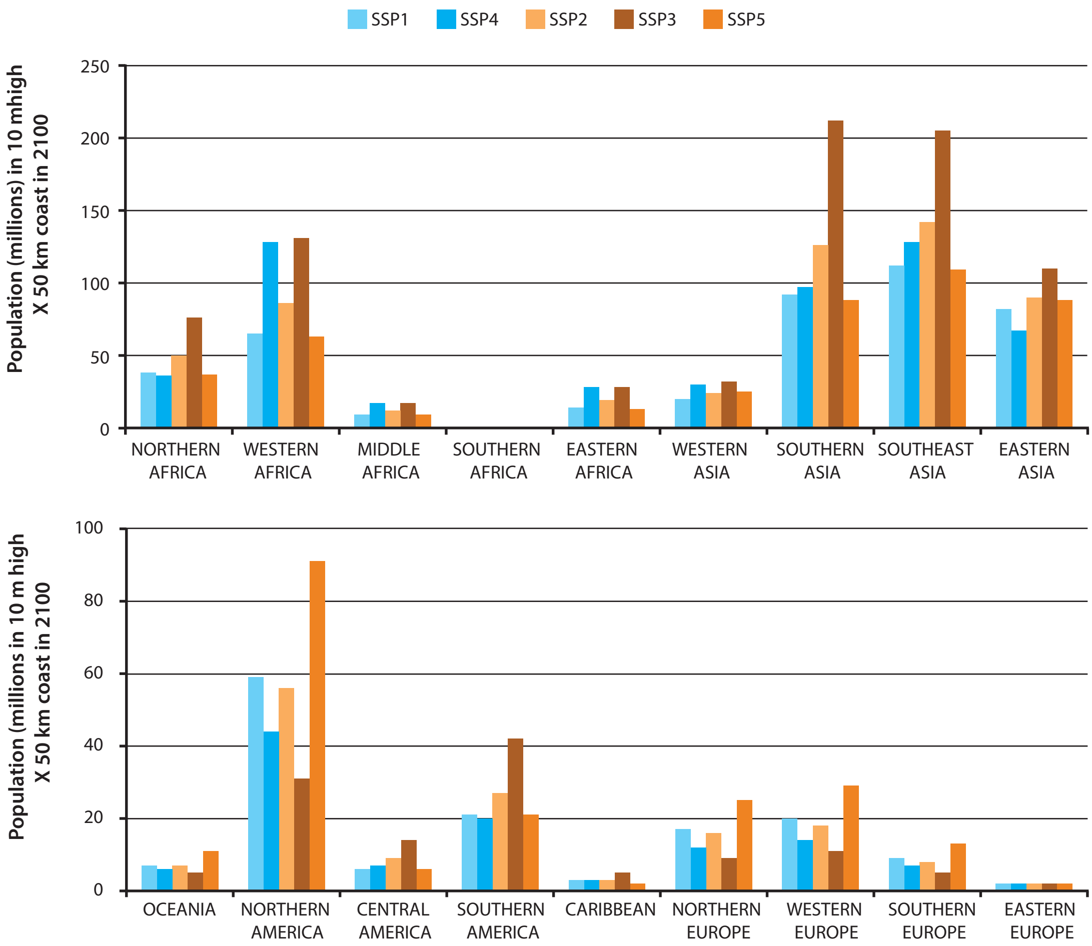


Table 4.3 Exposure metrics. Distribution of population in 2100 at 10 m elevation by SSP and by distance from shore. SSP1 and SSP4 are consistent with low emission scenarios (RCP4.5); SSP2, SSP3, and SSP5 are consistent with high emission scenarios (RCP8.5).

Region	SSP	Population 2100 at 10 m elevation			Region	SSP	Population 2100 at 10 m elevation		
		≤ 10 km	≤ 30 km	≤ 50 km			≤ 10 km	≤ 30 km	≤ 50 km
Northern Africa	SSP1	18 921 508	28 377 924	37 638 229	Oceania	SSP1	5 672 756	6 842 438	6 947 599
	SSP4	18 282 806	27 251 694	35 930 284		SSP4	4 984 728	6 009 662	6 107 938
	SSP2	25 274 792	37 941 185	50 361 098		SSP2	5 540 517	6 673 059	6 777 230
	SSP3	38 339 921	57 515 168	76 259 132		SSP3	3 750 129	4 475 109	4 547 566
	SSP5	18 336 766	27 510 562	36 512 449		SSP5	8 928 994	10 799 733	10 964 779
Western Africa	SSP1	27 664 878	49 551 338	64 508 737	Northern America	SSP1	34 306 200	55 983 986	59 151 247
	SSP4	55 143 310	98 186 754	128 248 835		SSP4	25 531 097	41 680 349	44 038 619
	SSP2	37 409 759	66 391 509	86 293 608		SSP2	32 195 829	52 560 434	55 534 294
	SSP3	56 095 045	100 016 761	130 719 691		SSP3	17 997 647	29 414 365	31 079 084
	SSP5	26 908 880	48 268 466	62 883 565		SSP5	52 901 299	86 235 760	91 113 188

Region	SSP	Population 2100 at 10 m elevation			Region	SSP	Population 2100 at 10 m elevation		
		≤ 10 km	≤ 30 km	≤ 50 km			≤ 10 km	≤ 30 km	≤ 50 km
Middle Africa	SSP1	6 344 423	8 803 852	9 123 719	Central America	SSP1	3 554 787	5 492 797	6 448 535
	SSP4	11 523 934	16 171 508	16 721 602		SSP4	4 399 961	6 500 707	7 468 287
	SSP2	8 409 515	11 773 382	12 188 677		SSP2	4 809 296	7 416 771	8 699 621
	SSP3	11 448 807	16 074 659	16 629 143		SSP3	7 936 055	12 233 985	14 350 346
	SSP5	6 399 044	8 879 108	9 199 010		SSP5	3 264 004	5 020 239	5 881 681
Southern Africa	SSP1	300,143	304 665	304,684	Southern America	SSP1	15 135 693	19 896 410	21 261 404
	SSP4	255,042	258 610	258,626		SSP4	14 419 048	18 984 376	20 328 187
	SSP2	355,352	360 694	360,717		SSP2	19 497 096	25 653 055	27 436 107
	SSP3	428,258	434 641	434,669		SSP3	29 729 748	39 209 220	42 036 736
	SSP5	316,358	321 146	321,167		SSP5	14 674 964	19 295 648	20 616 200
Eastern Africa	SSP1	12 266 097	13 680 955	13 882 315	Caribbean	SSP1	2 311 275	2 604 206	2 641 798
	SSP4	24 462 134	27 155 641	27 522 832		SSP4	2 689 449	2 999 490	3 035 534
	SSP2	17 199 837	19 138 480	19 408 497		SSP2	2 825 665	3 196 285	3 245 600
	SSP3	25 188 042	27 939 072	28 312 678		SSP3	4 480 926	5 094 307	5 177 595
	SSP5	11 755 896	13 131 036	13 328 041		SSP5	2 047 991	2 307 726	2 341 681
Western Asia	SSP1	15 902 381	18 286 937	19 863 776	Northern Europe	SSP1	11 836 856	14 984 688	16 535 033
	SSP4	23 130 757	27 543 133	29 749 206		SSP4	8 261 444	10 488 256	11 581 930
	SSP2	19 443 580	22 559 362	24 532 687		SSP2	11 212 176	14 219 741	15 684 222
	SSP3	24 839 674	29 403 468	32 336 333		SSP3	6 636 674	8 493 075	9 328 686
	SSP5	20 530 491	23 204 401	25 012 617		SSP5	17 885 491	22 606 353	24 961 713
Southern Asia	SSP1	47 976 665	76 228 125	92 106 690	Western Europe	SSP1	9 231 124	16 780 785	19 813 852
	SSP4	52 428 398	81 201 138	97 219 482		SSP4	6 591 287	11 978 638	14 143 319
	SSP2	65 988 530	104 572 861	126 203 985		SSP2	8 566 617	15 564 839	18 370 727
	SSP3	111 427 754	175 957 292	211 985 040		SSP3	5 049 534	9 195 880	10 848 562
	SSP5	45 952 038	72 747 852	87 725 184		SSP5	13 382 293	24 248 090	28 624 289
Southeastern Asia	SSP1	60 049 935	95 171 376	111 593 598	Southern Europe	SSP1	6 881 471	8 040 619	8 500 623
	SSP4	73 914 139	111 693 973	128 196 473		SSP4	5 311 805	6 204 957	6 558 300
	SSP2	76 809 254	121 518 967	142 233 682		SSP2	6 431 026	7 525 358	7 952 876
	SSP3	110 946 639	175 218 072	205 088 823		SSP3	3 969 060	4,684,651	4 939 313
	SSP5	58 693 429	92 811 127	108 817 286		SSP5	10 178 438	11 841 677	12 521 245
Eastern Asia	SSP1	33 200 207	65 879 638	82 014 203	Eastern Europe	SSP1	1 028 245	1 860 839	2 495 193
	SSP4	26 548 726	53 133 901	66 679 327		SSP4	876 574	1 626 795	2 187 617
	SSP2	35 533 367	71 545 648	90 051 796		SSP2	1 193 064	2 233 035	3 005 348
	SSP3	41 001 230	85 533 444	110 253 682		SSP3	1 326 848	2 563 169	3 450 585
	SSP5	36 998 973	71 961 049	88 395 612		SSP5	1 187 312	2 114 644	2 835 841

2100, modelled results indicate that 88 countries in SSP1 (Sustainable World) and 83 countries in SSP5 (Fossil-fuel led development) are projected to reach the aspirational goalpost of 100 years life expectancy. SSP2 (Middle of the Road) prescribes medium health investment resulting in a global mean of 86.1 years compared to 97.6 years for SSP1 and 97.7 for SSP 5. SSP4 (Inequality) features unequal health investments within regions with lower inputs in low-income countries, and medium investments in high-income countries, achieving a global mean life expectancy of 73.4 years by 2100. SSP3 is projected to reach the lowest life expectancy with a global mean of 71.8 years by 2100 given the low health investment in its narrative. For perspective, the 2014 HDI maximum goalpost for health is 85 years and the minimum is 20 years.

The mean years-at-school (MYS) metric is a contemporary measure of educational achievement and a useful gauge in future well-being scenarios (Figure 4-46C). In the SSP1 and SSP5 narratives, educational achievements are projected to be high, reaching 12.5 years and 12.4 years, respectively by 2100, allowing for completion of secondary education. For SSP2, moderate education levels are achieved with MYS reaching 11 years, a little short of the time required to obtain a high-school diploma. In SSP4 (Inequality), high fertility countries achieve very low education goals with uneven distribution; low fertility countries reach low education goals with uneven distribution; and OECD countries achieve medium goals, also with uneven distribution. The resulting projected global mean for SSP4 is 6.7 years, which is slightly longer than required to complete elementary education. SSP3 (Stalled development) is projected to achieve very low levels of education with a global MYS of 6.3 years.

A gender-sensitive education metric that has not yet been integrated in contemporary HDI is the proportion of females of childbearing age with tertiary level of education relative to the female population of the same age group (20-39 years of age) (Figure 4.46D). Because of the strong correlation between high female educational achievement and low fertility (Samir and Lutz 2014; Lutz et al. 2014), the role of female education in increasing well being and resilience at the household level appears as a logical policy target. We set a maximum goal post of 70 per cent for the 90-year period, with the highest proportion reached across the 5 SSP scenarios by 2100. SSP1 and SSP5 follow identical trajectories, SSP1 reaching a global mean of 64 per cent by 2100, and SSP5 reaching 65 per cent. SSP2 is projected to lag, at 50 per cent. The Inequality World of SSP4 is projected to achieve a global mean of 23 per cent and the Stalled Development scenario of SSP3 shows a reduced global mean of 11 per cent compared to the 2010 mean of 16 per cent, a decrease in female education achievement 90 years into the future. In this study, this measure is used as a second education metric in the construction of the HDI, replacing the measure Expected Years at School used in present HDI, for which projections by SSP are not available.

A third education measure is the Gender Gap in Education Attainment, which is the ratio of male to female 25 years and older (Figure 4.46E). Like the metric above, gender-sensitive indicators focus on the abilities of the female populations to assume their critical reproductive and quality-of-life enhancing roles at household and societal levels. Both SSP1 and SSP5 reach a global mean ratio of 0.97 (males/female) by 2100, meaning that females exceeded males in education for the age group 25 years and older. For the Middle of the Road scenario of SSP2, a global mean ratio of 0.99 males/female is achieved. For the Inequality narrative of SSP4, a sizeable gender gap is projected to exist at 1.06 males per female. For the Stalled Development pathway of SSP3, the ratio increases to 1.09 males per female.

The education metrics examined above show that in the narratives of SSP4 (Inequality) and SSP3 (Stalled Development), MSY and educational accomplishment of the female population are projected to decrease, as well as increases in the education gender gap. The manifestations of these will be more pronounced among developing countries and is discussed in greater detail below.

Per-capita GDP is a standard metric of human development. Figure 4.46F shows that wealth is projected to increase across all 5 reference SSPs. The Fossil-led Development scenario of SSP5 is projected to have the highest mean global GDP at 2005 US$1 X 1015 PPP by 2100. The Sustainable World scenario of SSP1 is projected to have high per-capita growth in low-income and medium-income countries and medium growth in high-income countries, all resulting in a global mean GDP of 2005 US$570 X 1012 PPP in 2100. The Middle of the Road SSP2 scenario has medium and uneven growth, reaching 2005 US$540 X 1012 PPP by 2100. The SSP4 Inequality scenario has low per-capita growth in low-income countries and medium in other countries, leading to a low global mean of 2005 US$360 X 1012 PPP by 2100. Finally for the SSP3 Stalled Development World, per-capita growth is slow, reaching a global mean of 2005 US$280 X 1012 PPP in 2100.

Figure 4.46. Vulnerability metrics. Global estimates of (a) population, (b) life expectancy at birth, (c) mean years at school, (d) %females of childbearing ages (20-39 years) with tertiary education, (e) gender gap in educational attainment, and (f) per capita GDP for the five reference Shared Socioeconomic Pathways (SSPs). SSPs are cohesive descriptions of socioeconomic development pathways that are used to examine future long-term scenarios in the search for effective measures to adapt to and mitigate climate change. SSP1 is called the Sustainability Pathway, SSP2 is Middle of the Road, SSP3 features regional rivalry, SSP4 highlights inequality, and SSP5 is fossil-fueled development (O'Neill et al 2015). Except for the average proportion of females with tertiary level education that is based on 143 modeled countries, the average metrics are based on 185 modeled countries (including coastal and landlocked).

Regional HDI Patterns in 2100. To examine the regional texture of the well-being metrics discussed above, a HDI is constructed at country scale annually over the period 2010-2100, combining life expectancy at birth, mean years at school, proportion of females of childbearing age with tertiary level education, and per-capita GDP, as discussed in the methods section. The country-scale HDIs are aggregated to derive the mean regional HDIs to conform with the coarse scale of land use and sea level rise measures, and are presented as time series. The current HDI classification scheme is used to compare the regions: 0.8+ (Very high); 0.7 ≤ HDI <0.8 (High); 0.55 < HDI < 0.7 (Medium); and HDI < 0.55 (Low) (HDR 2014).

Figure 4.47 shows the regional HDI time series for each SSP and regions in Oceania, the Americas, the Caribbean and Europe. In all SSPs, HDIs at country and regional scales are projected to increase during the 90-year period at varying rates depending on the SSP narrative. In SSP5, all regions reach Very high HDI by 2100, with very high carbon footprint and little attention to alternative fuel sources. In contrast, SSP1 also projects Very high HDI for countries to be achieved with low carbon footprint, using technology to increase efficiency and harnessing energy from renewables. In SSP2, HDIs range from 0.798 (High, Caribbean) to 0.938 (Very high, Western Europe), by 2100, a trend reflecting the medium investments made in human development. SSP4, the Inequality development pathway, projects HDI ranges in 2100 to reach 0.597 (Caribbean) to 0.804 (Western Europe)(classified as Medium to Very high). The wide disparity in 2100 HDI values exemplify the inequality that marks this scenario. Finally, the Stalled Development Scenario SSP3 has the worst projections for 2100: from 0.52 (Caribbean, Low) to 0.786 (Western Europe, High).

Figure 4.47. Vulnerability metrics. Regional HDI from 2010 to 2100 for Oceania, the Americas, Caribbean and Europe, integrating country-scale metrics for life expectancy at birth, mean years at school, percentage of females achieving tertiary education relative to total female population for ages 20-39 years, and per capita gross domestic product at 2005 PPP US$. A country's national population relative to the regional total population weights the country HDI each year. The sum of weighted country HDIs for a region provides the regional HDI per year.

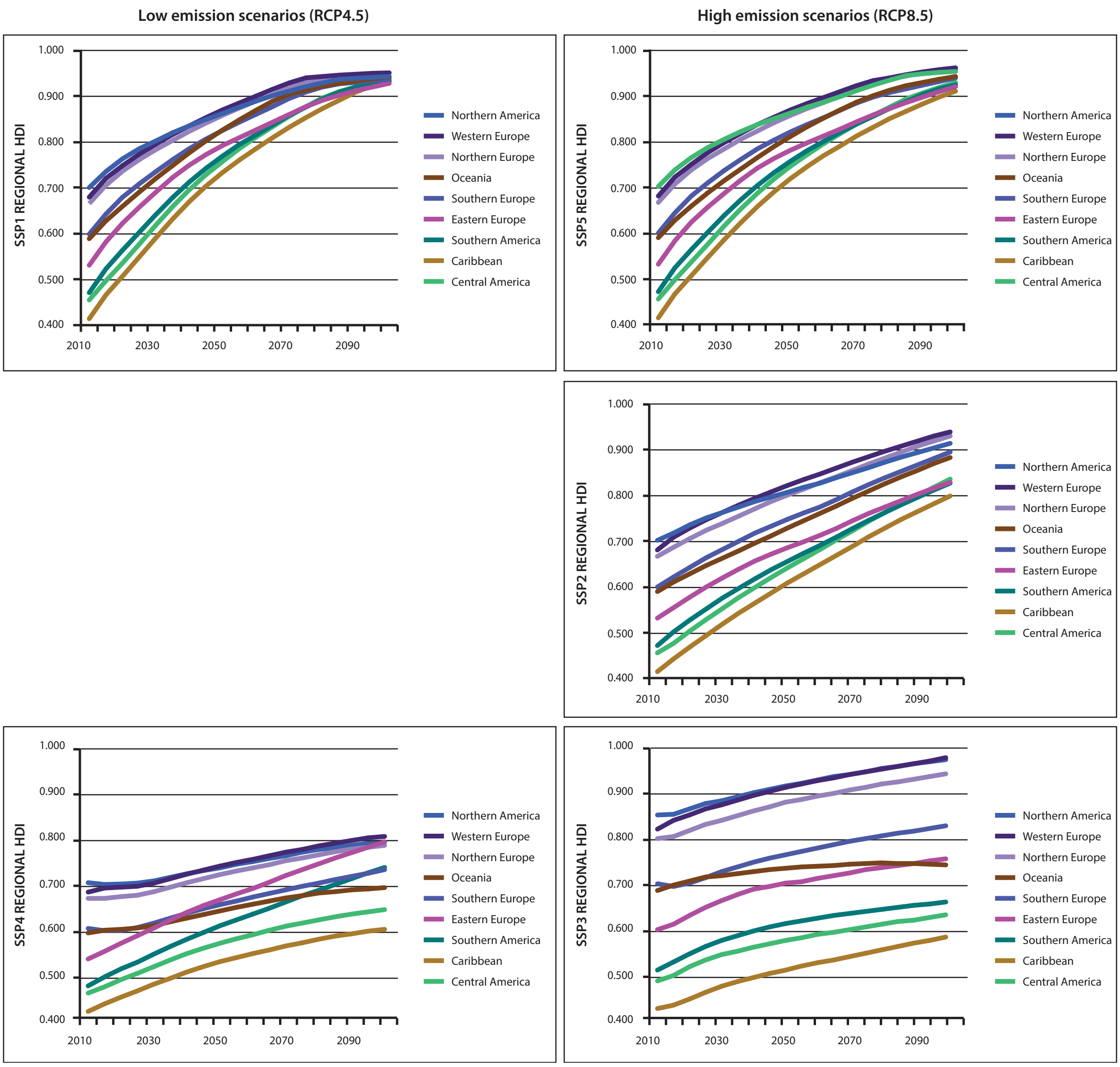
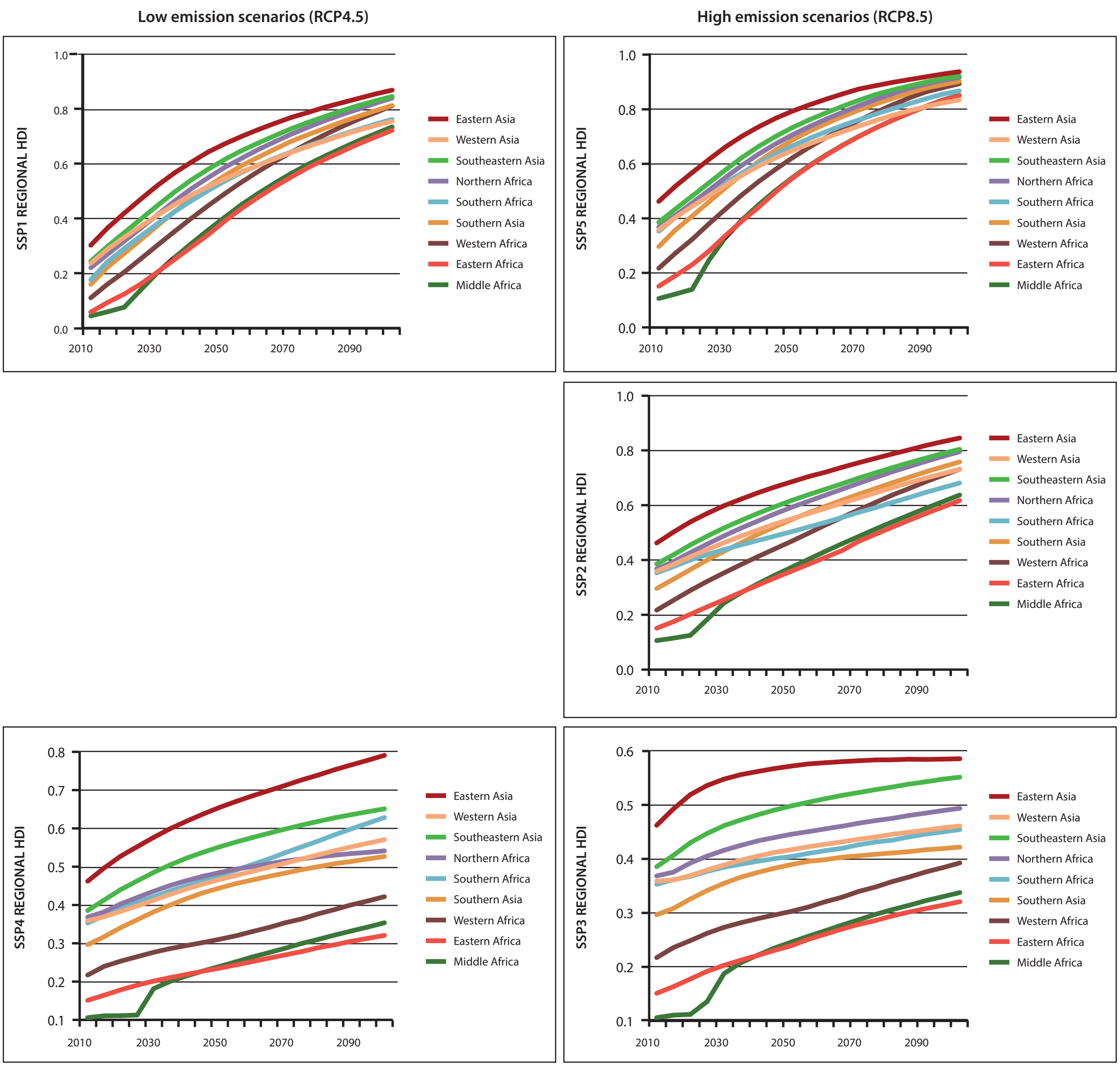


Figure 4.48 shows the HDI time series across all five SPPs for regions in Africa and Asia. Like their counterparts in the West, all countries and regions across all SSP narratives are projected to increase in HDI, albeit at varying rates consistent with the SSP features. Across all five SSP scenarios, during the 90-year projection period, Eastern and Southeastern Asia are projected to be consistently in the lead, and with Middle and Eastern Africa projected to be the least developed. SSP1 and SSP5 are both projected to bring all regions to Very high HDI levels by 2100. In the Inequality Pathway of SSP4, Eastern Africa, Middle Africa, Western Africa, Southern Asia and Northern Africa, in the order of increasing HDI values, are projected to be Low HDI countries, i.e. with HDI levels lower than 0.55. Under the Stalled Development narrative of SSP3, all regions have decreased rates of HDI progress, with Eastern and Southeastern Asia reaching Medium level, while Eastern Africa, Middle Africa, Western Africa, Southern Asia, Southern Africa, Western Asia and Northern Africa, in increasing HDI values, are all projected to be Low HDI by 2100.

Figure 4.48. Vulnerability metrics. Regional HDI from 2010 to 2100 for Africa and Asia, integrating country-scale metrics for life expectancy at birth, mean years at school, percentage of females achieving tertiary education relative to total female population for ages 20-39 years, and per capita gross domestic product at 2005 US PPP$. A country's national population relative to the regional total population weights the country HDI each year. The sum of weighted country HDIs for a region provides the regional HDI per year.



Regional patterns in the educational achievements of the female population to 2100. As a new metric in the calculation of HDI, we examine the trends in the proportion of females at childbearing age (20-39 years) in each of the SSPs, as shown in Figures 4.49 (Western regions) and 8 (Eastern Regions). Like the global patterns of the education metrics within the 90-year projection period, we note that the proportion of females with tertiary education increases in SSP1, 2, and 5, and are projected to come close to or meet the aspirational goal of 70 per cent. In SSP 4, developed regions show projected decreases while developing regions show increases, though nowhere near the goal standard of 70 per cent. In SSP3, all regions with the exception of Southeastern Asia are projected to decrease in this metric. Thus despite the overall projected trend of increasing HDI in all countries and regions for all SSPs, there are scenarios where gender-sensitive education indicators are projected to decrease, which may contribute to an increase in socioeconomic vulnerability. Female educational attainment has been shown to have profound impacts on household capacities and choices relevant to child health and mortality, household energy consumption and adaptation, and even the quality of participation in governance and democratic processes (Samir and Lutz 2014; Lutz et al. 2014). Enabling and empowering women is strategic in enhancing adaptive capacities to environmental risks including that resulting from SLR, at household and country scales.

Figure 4.49. Vulnerability metric. The proportion of females with tertiary education among females 20-39 years old (childbearing years), is examined for its role in increasing wellbeing and reducing overall socioeconomic vulnerability across all SSP futures. This panel series shows trends for the period 2010 to 2100 in the Americas, Europe, Oceania, and the Caribbean.

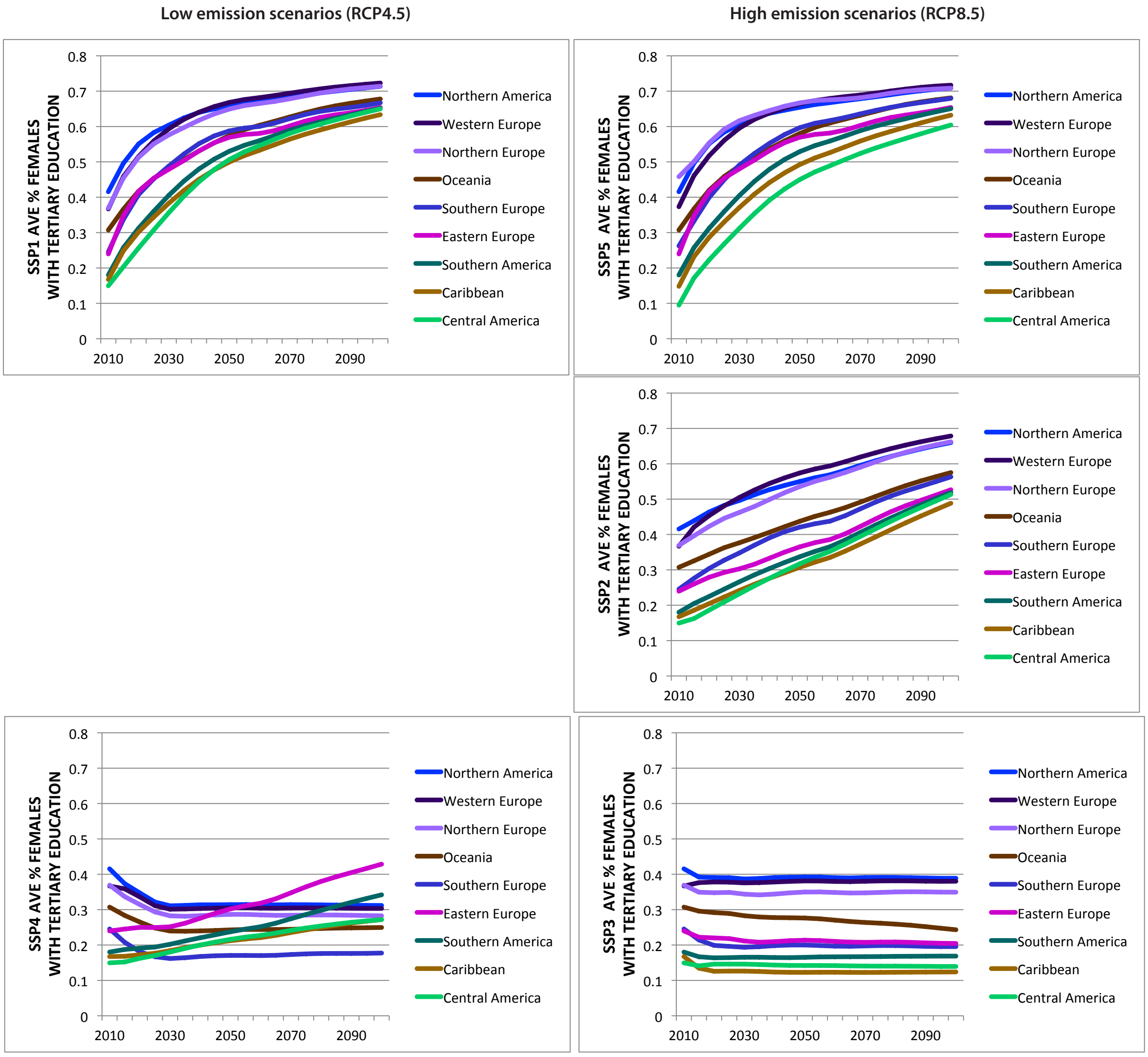
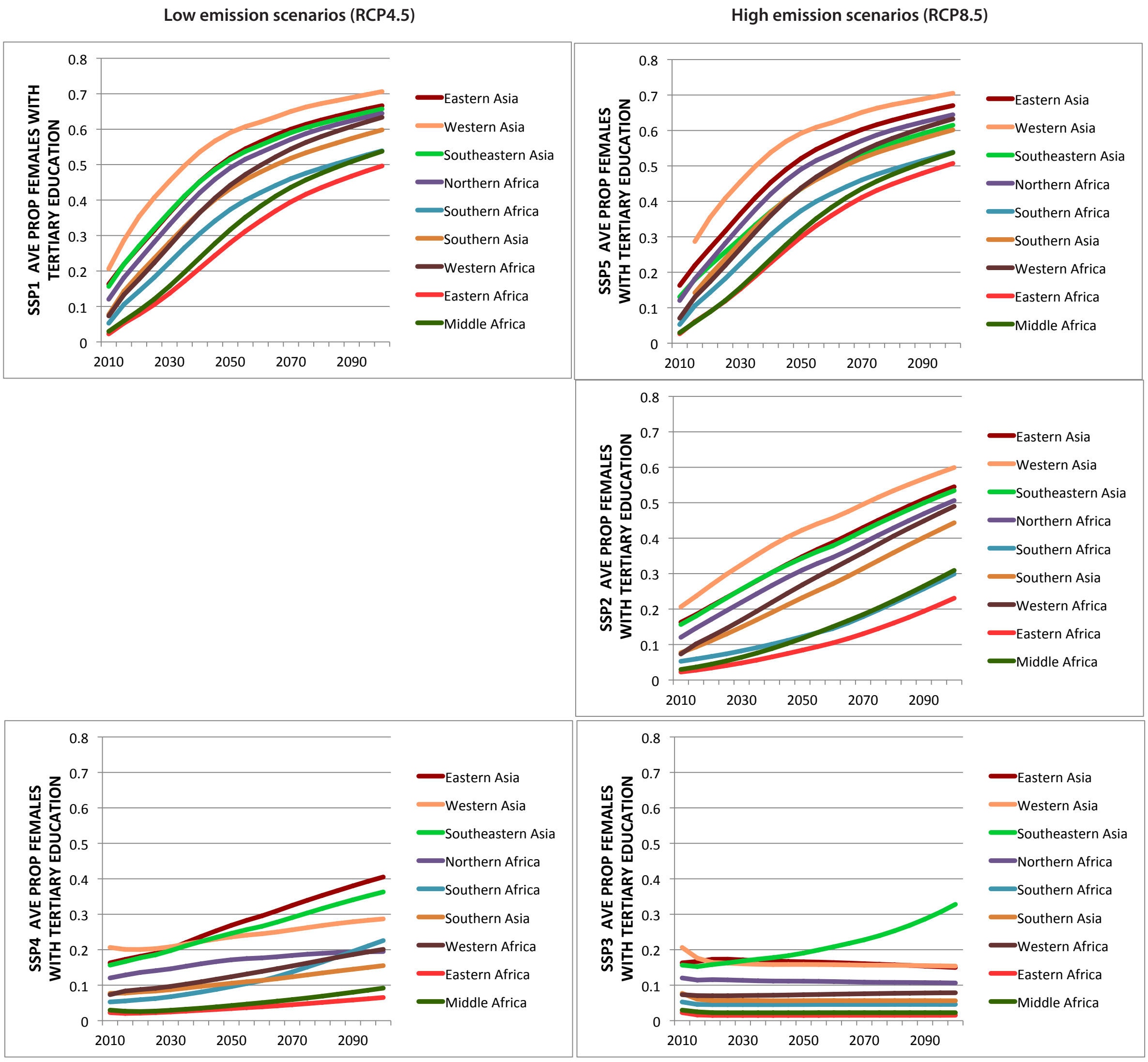


Figure 4.50. Vulnerability metric. The proportion of females with tertiary education among females of childbearing ages (20-39 years old) is examined for its role in increasing wellbeing and reducing overall socioeconomic vulnerability across all SSP futures. This panel shows trends for the period 2010 to 2100 in Africa and Asia.

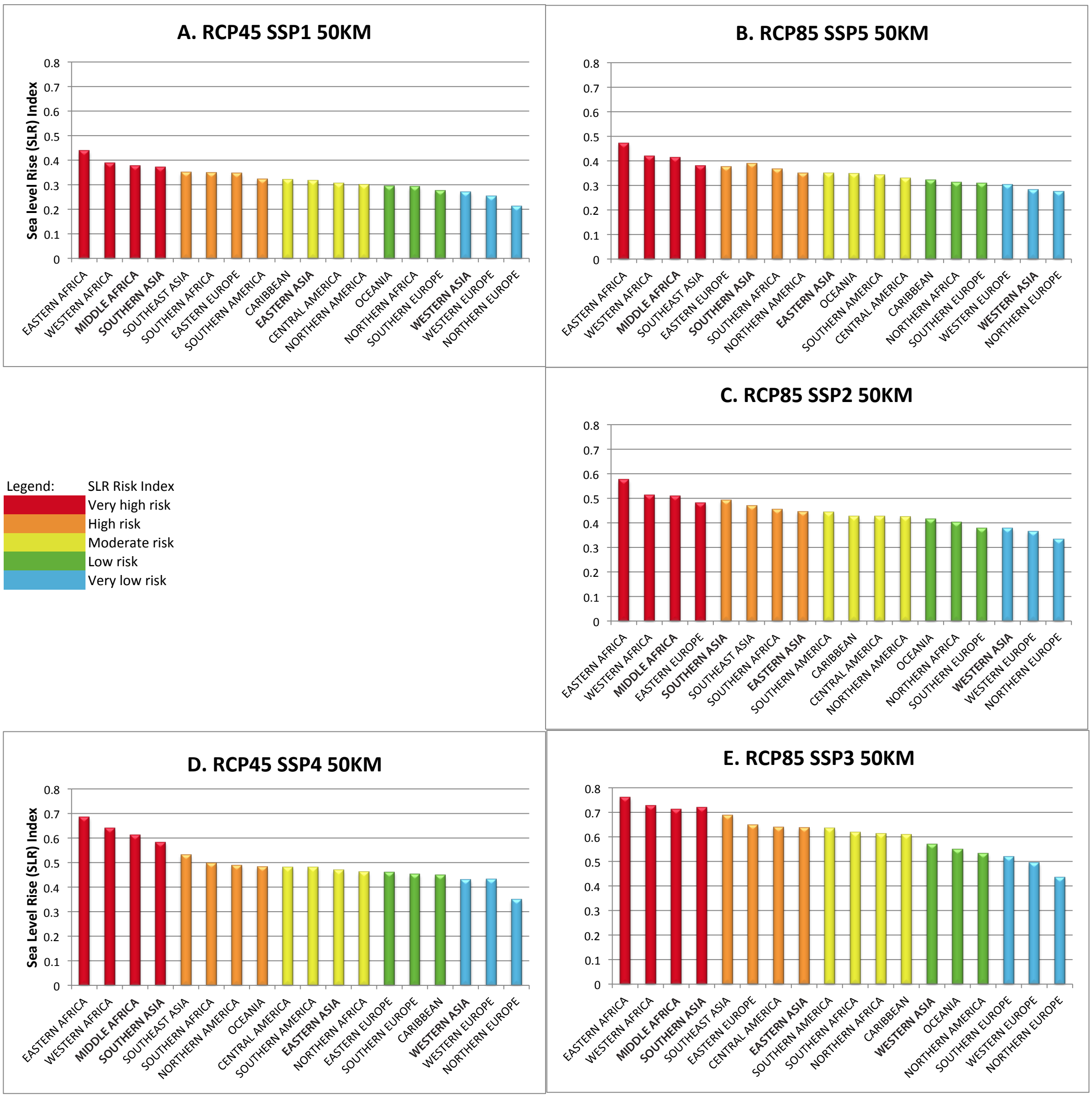


Regional patterns in SLR risk index. Within a hazard-exposure-vulnerability framework, the estimated SLR, populations and land-use areas under two emission scenarios (RCP 8.5 and RCP4.5) and the levels of development explored under the five SSP narratives (SSP1 to 5) are used to examine risk to SLR (Figure 4.51). Correlation analyses show that the hazard, exposure and vulnerability metrics are not correlated (none exceeding 36%) across the five reference scenarios (Table 4.4). Their geometric means are used to compute risk, which are significantly influenced by HDI Gap at 78 to 81%, despite its equal computational weight with hazard and exposure metrics.

Risk in this assessment integrates the combined measure of exposed population and total land area within the 10 m elevation X 50 km distance from shore, the estimated SLR, and the HDI Gap. Across SSPs, land area and maximum SLR are the same for a country or region, while population and HDI GAP vary in conformity with the SSP elements. The inclusion of the HDI Gap in risk index construction follows the concept that exposure and hazard metrics are necessary but insufficient determinants of risk. An important consideration is that risk is borne differently by populations at different levels of human development and wellbeing. Climate-related risks are additional burdens for development-compromised populations.

In a low emission scenario, SSP1 risk levels were consistently lower than SSP4 risk levels, and consistently the lowest across all five SSPs. In a high emission scenario, SSP5 consistently has the lowest risk values compared to SSP2 and SSP3. Across all five SSPs, SSP5 is a close second to SSP1. The interplay between emissions and sea level and the ability to localize the SLR estimates are key to refining the SLR risk associated with each scenario. Greenhouse gas emissions therefore serve as the ultimate reference point for what is sustainable, including the extent to which human wellbeing may be enhanced. SSP5, with a high emission scenario, is less sustainable than SSP1 without any policy intervention, even if all SSP5 HDI elements are virtually identical with their SSP1 counterparts, except SSP5 GDP, which is significantly higher than SSP1 GDP. Thus the only significant difference between SSP1 and SSP5 is the emission scenario associated with each.

Figure 4.51. The Sea Level Rise (SLR) Index by region, sorted from highest to lowest for each of the five development scenarios. The regions are grouped into five relative risk levels, with the top 4 classified as Very High Risk; the next 4 regions as High Risk; the next 4 as Moderate Risk; the next 3 as Low Risk; and the last 3 as Very Low Risk. Eastern, Western and Middle Africa consistently rank as the top three most vulnerable regions across all 5 scenarios.



In a low emission scenario, SSP4 has significantly increased risk levels, and is second highest in magnitude. Thus, even if emissions are low, the larger differences in human development among countries increase overall risk, which will impede the abilities of societies to adapt to climate change.

Across the five SSPs examined here, Eastern, Western and Middle Africa show the highest risk levels (Figure 4.51). Countries ranked from highest to lowest risk on average across 5 scenarios, are shown in Annex Table 3. The ten countries most at risk in 2100, in decreasing order, are: Somalia, Mozambique, Madagascar, Angola, Liberia, Sierra Leone, Papua New Guinea, Senegal, Guinea-Bissau and Mauritania. Seven of these countries also rank among the top 10 most vulnerable, validating the high correlation between vulnerability and risk. The reduction of risk through improved education, health and income are key. At the same time, the fundamental physical triggers of ocean warming and sea level rise highlight that reduction of carbon emissions is equally critical. Given the lag time between emissions and the earth's response to them, an integrated strategy would be one where human development is pursued not in isolation but within a framework of a sustainable planet where clear limits to greenhouse gas emissions have to be primary and central to any development strategy for both developing and developed economies.

Table 4.4. Correlation matrices among SLR Risk component metrics for each future development pathway, n=139 coastal countries. Among the 3 metrics, vulnerability measured by the Human Development Index Gap (i.e. 1-HDI), correlated the most with SLR Risk at 79 per cent at SSP3 pathway (Stalled Development) to 85 per cent at SSP4 pathway (Inequality).

RCP 4.5					RCP8.5				
SSP1	**Hazard**	**Exposure**	**Vulnerability**	**SLR Risk**	**SSP5**	**Hazard**	**Exposure**	**Vulnerability**	**SLR Risk**
Hazard	1.0000	0.1493	0.2791	0.5096	Hazard	1.0000	0.2246	0.3395	0.5302
Exposure	0.1493	1.0000	0.0065	0.4989	Exposure	0.2246	1.0000	0.0443	0.5671
Vulnerability	0.2791	0.0065	1.0000	0.8140	Vulnerability	0.3395	0.0443	1.0000	0.8127
SLR Risk	0.5096	0.4989	0.8140	1.0000	**SLR Risk**	0.5302	0.5671	0.8127	1.0000
					SSP2	**Hazard**	**Exposure**	**Vulnerability**	**SLR Risk**
					Hazard	1.0000	0.2523	0.3436	0.5533
					Exposure	0.2523	1.0000	0.0406	0.5969
					Vulnerability	0.3436	0.0406	1.0000	0.7909
					SLR Risk	0.5533	0.5969	0.7909	1.0000
SSP4	**Hazard**	**Exposure**	**Vulnerability**	**SLR Risk**	**SSP3**	**Hazard**	**Exposure**	**Vulnerability**	**SLR Risk**
Hazard	1.0000	0.1723	0.2704	0.4978	Hazard	1.0000	0.2793	0.3553	0.5692
Exposure	0.1723	1.0000	0.1397	0.5780	Exposure	0.2793	1.0000	0.1053	0.6544
Vulnerability	0.2704	0.1397	1.0000	0.8459	Vulnerability	0.3553	0.1053	1.0000	0.7883
SLR Risk	0.4978	0.5780	0.8459	1.0000	**SLR Risk**	0.5692	0.6544	0.7883	1.0000

To avert dire sea level rise scenarios in 2100 as evaluated by Church et al. (2013), and notwithstanding a potential for higher sea level rise resulting from unquantified and abrupt melting of significant masses of ice sheets, the explorations of basic scenarios of human development point to key strategies. Steering away from conditions prescribed by SSP3 (high emission, Regional Rivalry), SSP4 (low emission, Inequality) and SSP2 (medium to high emission, Middle of the Road) appears prudent. Burke et al. (2015) project that 5 per cent of countries may become poorer in 2100 than today in RCP 8.5 and SSP5, and 43 per cent may become so in RCP 8.5 and SSP3. The SSP1 narrative cohesive with a low emission scenario appears to fulfil both the biophysical requirement to maintain low concentrations of greenhouse gases and the socioeconomic requirement to enhance human well being among least developed countries.

In evaluating the RCP options and sea level rise, Hansen et al. (2015) stress that a 2°C warming above pre-industrial level is beyond the radiative forcing the earth has faced in previous glacial-interglacial cycles, implying a target emission scenario that must necessarily be lower than prescribed by RCP 4.5, i.e. RCP 2.6. In the latter scenario, radiative forcing reaches 3.1 W/m^2 by 2050, stabilizing to 2.6 W/m^2 by 2100, with a CO_2 equivalent greenhouse concentration of 490 ppm and a resulting temperature increase of 1.5°C. Sanford et al. (2014) warn that current emissions are tracking dangerously close to RCP 8.5. To initiate a climate policy that must address high emission scenarios, science needs to convey that RCPs and SSPs cannot be weighted in the same way by virtue of the risks they carry for the planet. In addressing the increasing probability of high emissions, climate policies at national, regional and global scales must weigh the costs and benefits of human development, alongside climate mitigation and adaptation, as well as all trade-offs necessary to meet very low emission targets, despite huge uncertainties. In addition, the time frames of concern must go beyond the reference year of 2100, because contemporary emissions underpin climate changes thousands of years into the future, including SLR. Clark et al (2016) envisions the evolution of energy infrastructure that features net-zero emissions so that climate change 10,000 years hence may be contained within the planet's habitable range. While climate science provides an analytical framework for the study of earth system change spanning geologic time, the social sciences would need to define plausible scenarios through which human societies can evolve an ethos for sustaining the earth system long-term that is across millennia.

4.5.3 Notes on methods

Table 4.5 describes the spatial data layers and tabular data used in this study.

2100 RCP 4.5 and RCP8.5 Regional Sea Level Change. Using the University of Hamburg Integrated Climate Data Center Live Access Server at http://www.icdc.zmaw.de/las/getUI.do, data and maps of the RCP4.5 and RCP8.5 total ensemble mean sea surface heights used in the IPCC AR5 (2013) were obtained. A geo-referenced sea surface height data layer at 1° resolution was analysed, together with a country population data layer, to obtain the minimum and maximum sea level change data for the nearest coastal grid cells adjacent to littoral states using GIS analysis for RCP4.5 and RCP8.5.

2100 Land areas in coastal areas distribution. To obtain estimates of total land area in coastal spaces defined by co-located elevations and distances from shore in 2100, we obtained the harmonized land-use data layer for RCP8.5 developed by Hurtt et al. (2011) using the MESSAGE Integrated Assessment Model. The RCP8.5 MESSAGE land-use model features gridded 0.5° X 0.5° land use transition time series for the period 2005-2100, and includes crop, pasture, and urban fractions for each 0.5° grid cell.

For this study, we focused on estimating total coastal land areas, while also obtaining land use data. However, the greatest drawback of the data set is that the coastlines of littoral states are not resolved within the outermost 0.5° grid cells other than the assignment of a country code. A major corrective exercise is implemented by this study to resolve borders of coastal states and minimize the inclusion of ocean water outside country borders before areas of land use could be derived at country scale. To do this, the population layer prepared by CIESIN (2013) with resolved coastlines was used to remove oceanic water from coastal grid cells of the land-use map in 2100. The remaining inland waters within the country borders were reconciled with the Global Lakes and Wetlands Database (GLWD) 3.0 data layer for lakes and wetlands. Reductions in water content of border cells created unclassified land fractions that were reallocated to cropland, pastureland, and primary and secondary vegetated land, following the land ratios after removal of excess oceanic water. For locations with permafrost and desert areas, we used permafrost and desert and dry (i.e. low moisture) biome maps to delineate these areas before allocating remaining fractions to land-use areas. The GLWD3.0 data layer, permafrost and desert maps reflect present-day conditions, which are assumed to remain constant to 2100, given the lack of projected data for these features. Details of the GIS analyses to obtain land areas by land use are in Annex Figure 1.

Table 4.5. Spatial data layers and tabular data used in this study.

Indicator Sub-theme	Indicator	Time Period	Underlying metrics	Data sources
I. Regional Sea Level change	Maximum sea level change at country scale	2100	Total ensemble mean sea surface height	http://www.icdc.zmaw.de/las/getUI.do
II. Population and Land Use	Coastal population by elevation up to 10 m and higher and by distance from shore up to 50km (spatial)	2100	Populations at ≤1, ≤2, ≤3, ≤4, ≤5, 5-10 m, ≥10m elevation; at 0-2km, 2-4km, 4-6km, 6-10km, 10-15km, 15-20km, 20-30km, 30-40km, 40-50km from shore; Resolution at 1 km (30 arc-seconds) with coastlines resolved	http://sedac.ciesin.columbia.edu/data/set/lecz-urban-rural-population-land-area-estimates-v2. (registration required);
	Country population	2010-2100 for all SSPs	Tabular data	Wittgenstein Centre for Demography and Global Human Capital 2014 at http://witt.null2.net/shiny/wittgensteincentredataexplorer/
	ACE2 Digital Elevation Model	2009	Used 1 km resolution	http://tethys.eaprs.cse.dmu.ac.uk/ACE2/ (registration required); Available at 3,9 and 30 sec and 5 min resolution; registration required
	Land Use Change RCP85 Scenario	2005-2100	Crop, Pasture, Urban, Primary and Secondary Vegetation; Resolution at 0.5 °	Hurtt et al. 2011; Data download at http://luh.umd.edu
	Global Lakes and Wetlands Database GLWD3.0 Layer	Present day	Inland water bodies to resolve coastal cells within national boundaries; resolution at 1 km	Lehner and Döll (2004); available for free download at http://www.worldwildlife.org/pages/global-lakes-and-wetlands-database
	Permafrost layers	Present day	Circum-arctic, Canada, China, Russia, USA Alaska	Global Geocryological Data System, University of Colorado National Snow and Ice Data Center; data downloads at http://nsidc.org/data/ease/data_summaries.html - frozen
	Desert layer	Present day	Desert and xeric biomes	Olson and Dinerstein. 2002. The Global 200: Priority ecoregions for global conservation.
III. Human wellbeing	HDI Metrics for 2100 using SSP pathways	2010-2100	Geometric Mean of Female Tertiary Education Achievement (20-39 years old), GDP per capita, Life expectancy	These metrics are used to compute country- and regional scale Human Development Index.
	Tertiary education for women of childbearing years (20-39 yrs old)	SSP1-5 for 2010-2100	Modelled population data	IIASA Population Model, SSP Database, 2012 Available at: https://secure.iiasa.ac.at/web-apps/ene/SspDb
	Gender Gap in Educational Attainment as ratio of males to females (25 yrs+ of age group with post secondary educational achievement) (Global averages)	2010-2100	Modelled data	Wittgenstein Centre for Demography and Global Human Capital 2014 at http://witt.null2.net/shiny/wittgensteincentredataexplorer/
	Mean years at school	SSP1-5 for 2010-2100	Modelled data	IIASA Population Model, SSP Database, 2012 Available at: https://secure.iiasa.ac.at/web-apps/ene/SspDb
	GDP per capita	SSP1-5 for 2010-2100	Modelled data on National GDP and Population	OECD GDP Model, SSP Database, 2012 Available at: https://secure.iiasa.ac.at/web-apps/ene/SspDb
	Life expectancy from birth	SSP1-5 for 2010 to 2100	Modelled data	Wittgenstein Centre for Demography and Global Human Capital 2014 at http://witt.null2.net/shiny/wittgensteincentredataexplorer/
IV. 2100 Sea Level Rise Risk Index	Geometric Mean of 2100 Area and Population in (10m X 10 km), Maximum sea level rise and HDI Gap	2100	Metrics derived from Modelled data and Index constructed as a natural disaster Index (risk =hazard X exposure X vulnerability)	As above

Because of the major data correction for coastal grid cells, and the two-dimensional (elevation by distance from shore) derivation of land and population distributions that demanded significant computer resources and supervised area reallocation algorithms, we focused on processing land-use data for one RCP pathway: RCP8.5. There is no other global land use data set for 2100 that could be used to calibrate the data we derived, and comparisons of coastal land uses under different RCPs may be possible in future.

We determined total land areas and area distribution at ≤1 m, ≤2 m, ≤3 m, ≤4 m, ≤ 5 m, 5-10 m, and >10 m elevation and, each of which were co-located at 0-2 km, 2-4 km, 4-6 km, 6-10 km, 10-15 km, 15-20 km, 20-30 km, 30-40 km, and 40-50 km from the shore, following the same protocol for obtaining population distributions. For reporting, we aggregate land-use areas by elevation to ≤10 m and >10 m, and by total elevation; and are intersected within ≤10 km, ≤30 km and ≤50 km coastal widths.

We used the total land area within the 10 m elevation and cumulative distances from shore to 10 km, to 30 km and to 50 km in the sea level risk calculation for RCP8.5, and assumed that the total cumulative land areas would be the same for RCP4.5. We use the total land area within the 10 m elevation co-located within the cumulative 50 km coastal width as area exposure for this global SLR risk assessment. Impacts of physical processes associated with SLR such as coastal erosion, floodplain inundation, storm surge are assumed to take place within this coastal space.

2100 Population distribution. Using the 1 km resolution 2100 population layer (CIESIN 2013) superimposed on the 1 km ACE2 Digital elevation model, we determined population distribution at ≤1 m, ≤2 m, ≤3 m, ≤4 m, ≤5 m, 5-10 m, and >10 m elevation and each elevation bin intersecting with widths at 0-2 km, 2-4 km, 4-6 km, 6-10 km, 10-15 km, 15-20 km, 20-30 km, 30-40 km, and 40-50 km from shore. Note that the spatially explicit location of population estimates by intersecting elevation and distance from shore allows for global comparisons by explicit location, which is not possible when coastal segments are defined at floodplain scales (Neumann et al. 2015). However, we note that the vertical resolution of the ACE2 Digital Elevation Model is coarser than the 1 m elevation intervals used in this study. Thus we report the results by ranges in elevations ≤10 m and >10 m and which conform with the 10 m elevation used by McGranahan et al. (2007) to discriminate low elevation coastal zones. For ease of tabulation, the distances from shore are aggregated to ≤10 km, ≤30 km and ≤50 km. The population distribution using the CIESIN (2013) data layer at coastal segment and country scales are used to distribute the SSP populations spatially in the 10m elevation - 50 km coastal space for 2100. We note that there are inherent uncertainties in spatially explicit population projections to 2100 and that current estimates may be refined with better spatial data in future.

Human well being by Shared Socioeconomic Pathway (1-5) from 2010 to 2100. Annex Table 2 details the elements of the five SSPs used in the study to determine trends in well being from present to the end of the century (O'Neill et al. 2104, 2015). For cohesive future scenarios, we combine SSP1 and SSP4 with RCP4.5 as future low emission scenarios, and SSP2, SSP3 and SSP5 with RCP8.5 as future high emission scenarios.

SSP1 features low population growth rate, and high achievements in education, health and economic growth. It has low challenges to mitigation, and the high degree of well being implies low challenges to adaptation.

SSP2 is called the Middle of the Road pathway, where conditions do not change significantly from historic trends. Progress in reaching sustainable development goals is slow, with no fundamental breakthroughs in technology. Global population growth is moderate, but education investments are not adequate to allow transition to low fertility rates in developing countries. This pathway has moderate challenges to mitigation and adaptation, with significant variance between and within countries.

SSP3 features a Regional Rivalry pathway. States focus on domestic needs for energy and food security. Education and technological development take a back seat, along with environmental concerns. Population growth is uneven: low in developed and high in developing economies. This pathway has high challenges to both adaptation and mitigation.

SSP4 features Inequality within and among countries. It has a widening gap between a globalized society and a group of low-income and poorly educated societies engaged in low-technology economies. This pathway has low challenges to mitigation but indicates high adaptation challenges as many remain at low levels of development.

SSP5 highlights Fossil Fuel led Development. It has strong investment in health and education, but also a preference for continued exploitation of fossil fuels, all factors leading to rapid economic growth. It features high challenges to mitigation, and low challenges to adaptation.

For each of the five reference SSPs, we obtain the modelled well-being metrics to compute a country-scale Human Development Index annually for each of 139 coastal countries over 2010-2100. The metrics include life expectancy at birth as a health metric, mean years at school and the percentage of women of childbearing age (20-39 years) with tertiary level education as education metrics, and per capita GDP as an economic metric (Dellink et al. 2015, Crespo 2015). These metrics are used to compute country-scale HDI as an indicator of well-being, and the resulting HDI Gap (1-HDI) as a metric of vulnerability.

We followed the current methods of computing HDI (HDR 2014), adjusting the current minimum and maximum metric goal posts to what may be relevant aspirational goals in 2100. We chose a gender-sensitive education metric, the percentage of females of childbearing age with tertiary education instead of expected mean years at school, the latter being one of the metrics for current HDI not quantitatively modelled within the SSP narratives.

The computations of the three sub- indices that make up the 2010-2100 HDI are:

Index	Normalized Metric	Minimum Goal Post	Maximum Goal Post	Data Sources
Health = Normalized E0	Life expectancy at birth or year 0, E0 = (E0 -20)/(100-20)	20 years	100 years	Lutz et al. 2014 (eds). http://www.oeaw.ac.at/vid/dataexplorer/
Education Index = Average (MYS, % Fem_Tert)	Mean years at school (= MYS /18)	0 years	18 years	Lutz et al. (2014) (eds). http://www.oeaw.ac.at/vid/dataexplorer/
	% Females of childbearing age with tertiary education (= % Fem_Tert / 70%)	0%	70%	Lutz et al. (2014) (eds). http://www.oeaw.ac.at/vid/dataexplorer/
Income = Normalized Per capita GDP	Per capita GDP in 2005 US$ PPP = (LN Income – LN 700) / (LN $100 000 – LN 700)	$700	$100 000	Dellink et al. 2015, Crespo 2015. https://secure.iiasa.ac.at/web-apps/ene/SspDb/dsd?Action=htmlpage&page=about

As a measure of well being, we compute the HDI as:

Human Development Index = Geometric Mean (Health Index, Education Index, Income Index)

We use HDI Gap as a measure of vulnerability caused by unfulfilled development potential, computed as:

HDI Gap = 1- HDI

2100 Sea Level Rise Risk Index by SSP. We develop the 2100 Sea Level Rise Risk Index to integrate the exposure of population and land area to sea level rise in the 10 m X 10, 30 and 50 km coastal zone, the maximum sea level rise for either RCP 4.5 (low emission scenarios) or RCP8.5 (high emission scenarios) at country scale, and the HDI Gap. The three metrics are not correlated at 36% and higher (Table 4).

For low emission scenarios (SSP1 and SSP4 with RCP4.5 sea level rise):

2100 Country Sea Level Rise Risk Index = (Natural logarithm (LN) of Total Area + LN Population)$_{\text{normalized across all 5 RCP-SSP combination scenarios}}$ X (RCP 4.5 Maximum Sea Level Rise) X (HDI Gap)

For high emission scenarios (SSP2, SSP3 and SSP5 with RCP8.5 sea level rise):

2100 Country Sea Level Rise Risk Index = (LN Total Area + LN Population)$_{\text{normalized across all 5 RCP-SSP combination scenarios}}$ X (RCP 8.5 Maximum Sea Level Rise) X (HDI Gap)

Since HDI Gap is derived from HDI values which were previously normalized, and sea level rise values are between 0 and 1, only the combined LN values for area and population were normalized prior to risk index computation. The natural logarithms of the combined land use and populations were normalized using the minimum and maximum values across the five RCP-SSP combination scenarios, so that the risk values are comparable across the five reference development pathways.

Scales for reporting results. All input and derived data for hazard, exposure and vulnerability metrics are at country scale, including associated rank scores. For ease of presentation, regional averages for SSP wellbeing metrics and risk were also computed using either country coastal populations or land areas as weighting factors, where appropriate. Annex Table 4 lists the 139 SSP countries and regions used in the analysis.

Within a combination RCP-SSP scenario, the country-scale and regional scale SLR Risk Indices increases between 0 and 5 percentage points, and between 0 and 3 percentage points, respectively, when the coastal width is increased from 10 km to 50 km since the natural logarithms of both area and population are used in risk calculations. Here we report the risk indices for the 50 km coast where exposure to and risk of sea level rise would subsume appropriate scales of physical (e.g. erosion, storm surge, flooding) and socioeconomic processes (e.g. coastal livelihoods, daily migrations). Refinements of spatial scales to widths and elevations of coastal floodplains may be done at finer scale analysis since the explicit co-location of elevation, area and populations provides analytical flexibility.

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Annex Table 1. Exposure metrics showing projected future land use and total land areas in 2100 at RCP8.5 derived from harmonized land use transition mapping by Hurtt et al (2011) using the RCP8.5 MESSAGE Integrated Assessment Model (http://luh.umd.edu). Total land area at 50km is used in the SLR Risk Index calculations.

REGION	Elevation	Agricultural Land (distance from shore, km²)			Urban Land (distance from shore, km²)			Vegetated Land (distance from shore, km²)			Total Area (distance from shore, km²)		
		≤10km	≤30km	≤50km	≤10km	≤30km	≤50km	≤10km	≤30km	≤50km	≤10km	≤30km	≤50km
NORTHERN AFRICA	≤10m	9 069	16 009	19 389	900	1 641	2 140	4 525	7 212	8 569	20 273	34 291	39 956
	>10m	37 868	124 408	205 400	3 072	8 826	13 353	24 760	102 671	190 831	68 788	243 289	420 648
	TOTAL	46 937	140 417	224 789	3 972	10 467	15 492	29 285	109 883	199 400	89 060	277 580	460 604
WESTERN AFRICA	≤10m	9 156	19 216	24 328	1 459	3 049	3 878	8 744	15 829	20 250	35 826	68 117	84 989
	>10m	7 698	40 956	85 029	955	4 687	9 439	7 661	28 628	52 488	19 594	81 319	155 861
	TOTAL	16 854	60 172	109 357	2 414	7 735	13 317	16 405	44 458	72 739	55 420	149 436	240 851
MIDDLE AFRICA	≤10m	5 312	14 881	20 294	456	1 211	1 379	4 969	14 886	24 342	14 786	38 962	55 123
	>10m	9 422	30 196	55 331	701	2 122	4 105	8 089	21 103	36 257	19 538	55 705	98 610
	TOTAL	14 733	45 077	75 626	1 157	3 333	5 484	13 058	35 989	60 599	34 325	94 667	153 733
SOUTHERN AFRICA	≤10m	1 309	1 514	1 517	33	39	39	2 075	2 136	2 136	4 327	4 779	4 789
	>10m	19 494	62 282	108 643	623	1 577	2 473	11 507	37 761	64 048	32 936	103 965	177 983
	TOTAL	20 803	63 797	110 160	656	1 616	2 512	13 582	39 897	66 184	37 264	108 744	182 772
EASTERN AFRICA	≤10m	23 186	31 872	33 841	718	855	869	3 713	5 443	6 379	43 355	60 917	65 577
	>10m	72 449	246 029	417 626	2 922	8 063	13 062	15 565	53 999	93 095	97 621	324 140	547 395
	TOTAL	95 636	277 901	451 467	3 639	8 918	13 931	19 278	59 441	99 474	140 976	385 057	612 972
WESTERN ASIA	≤10m	8 890	12 386	13 392	1 186	1 345	1 428	17 009	23 829	25 490	43 872	57 792	62 025
	>10m	33 983	128 328	230 252	4 567	13 839	19 767	58 321	196 675	322 504	107 708	358 396	596 875
	TOTAL	42 872	140 714	243 644	5 752	15 184	21 196	75 330	220 504	347 994	151 579	416 188	658 901
SOUTHERN ASIA	≤10m	18 005	35 072	43 950	1 763	3 123	3 833	11 154	17 261	19 507	60 165	101 583	122 198
	>10m	15 787	61 296	112 117	1 949	7 056	12 401	22 040	70 697	122 545	44 597	158 172	284 539
	TOTAL	33 791	96 369	156 067	3 713	10 179	16 234	33 194	87 958	142 052	104 762	259 755	406 737

REGION	Elevation	Agricultural Land (distance from shore, km^2)			Urban Land (distance from shore, km^2)			Vegetated Land (distance from shore, km^2)			Total Area (distance from shore, km^2)		
		≤10km	≤30km	≤50km	≤10km	≤30km	≤50km	≤10km	≤30km	≤50km	≤10km	≤30km	≤50km
SOUTHEASTERN ASIA	≤10m	47 270	82 264	99 296	4 600	7 161	7 988	78 772	133 981	162 827	189 821	327 242	397 495
	>10m	123 654	308 493	436 010	9 948	26 396	38 961	256 168	606 289	858 655	438 254	1 018 674	1 422 119
	TOTAL	170 924	390 757	535 306	14 547	33 557	46 950	334 939	740 270	1 021 482	628 075	1 345 915	1 819 614
EASTERN ASIA	≤10m	14 933	31 971	44 427	3 377	7 755	10 963	19 628	36 654	47 450	53 331	101 846	131 532
	>10m	31 315	83 950	129 408	5 831	14 946	21 771	92 045	233 337	343 097	136 056	341 228	504 346
	TOTAL	46 248	115 921	173 835	9 208	22 701	32 734	111 672	269 992	390 547	189 388	443 073	635 877
OCEANIA	≤10m	35 287	56 755	62 447	1 099	1 442	1 490	30 040	46 955	51 181	107 551	163 083	176 628
	>10m	114 829	355 536	587 152	3 813	9 955	13 330	173 696	389 655	527 916	323 322	797 276	1 175 341
	TOTAL	150 116	412 290	649 599	4 912	11 397	14 820	203 736	436 610	579 097	430 873	960 358	1 351 968
NORTHERN AMERICA	≤10m	6 885	10 688	15 092	3 169	4 653	4 993	140 717	146 984	148 946	299 803	420 097	480 049
	>10m	23 290	49 303	71 008	6 640	15 364	21 222	861 505	1 643 182	2 116 398	1 195 594	2 428 197	3 257 609
	TOTAL	30 175	59 991	86 099	9 809	20 017	26 215	1 002 223	1 790 166	2 265 343	1 495 397	2 848 294	3 737 658
CENTRAL AMERICA	≤10m	23 709	47 218	57 268	663	1 178	1 392	19 650	37 474	45 585	58 835	108 614	128 015
	>10m	40 200	149 896	257,598	1 375	5 044	8 323	39 750	141 232	225 882	87 843	306 914	504 477
	TOTAL	63 909	197 115	314,866	2 038	6 223	9 715	59 401	178 706	271 468	146 679	415 528	632 492
CARIBBEAN	≤10m	9 001	10 839	11 285	729	787	803	11 434	13 032	13 168	36 511	43 593	44 339
	>10m	24 584	74 981	103 427	2 731	6 493	7 409	18 642	43 916	52 345	47 537	127 345	165 207
	TOTAL	33 585	85 820	114 711	3 459	7 280	8 213	30 076	56 948	65 513	84 048	170 938	209 546
SOUTHERN AMERICA	≤10m	35 244	59 996	74 538	1 775	2 795	3 202	37 433	63 317	79 181	112 336	204 139	260 002
	>10m	91 138	295 765	500 487	4 350	13 844	21 551	149 528	346 001	514 825	257 336	682 767	1 077 492
	TOTAL	126 382	355 761	575 025	6 125	16 639	24 753	186 961	409 317	594 006	369 673	886 907	1 337 494
NORTHERN EUROPE	≤10m	13 864	19 009	21 780	1 395	1 901	2 103	35 893	42 653	44 370	56 955	70 172	75 158
	>10m	53 387	134 911	190 630	4 097	10 076	13 432	150 066	347 094	500 861	219 052	510 220	728 552
	TOTAL	67 251	153 920	212 410	5 492	11 977	15 535	185 959	389 747	545 231	276 007	580 392	803 710

REGION	Elevation	Agricultural Land (distance from shore, km²)			Urban Land (distance from shore, km²)			Vegetated Land (distance from shore, km²)			Total Area (distance from shore, km²)		
		≤10km	≤30km	≤50km	≤10km	≤30km	≤50km	≤10km	≤30km	≤50km	≤10km	≤30km	≤50km
WESTERN EUROPE	≤10m	11 003	20 133	24 284	1 650	3 152	3 784	9 281	15 432	17 924	27 608	46 037	53 405
	>10m	14 377	45 203	74 214	1 533	4 222	6 269	18 099	49 996	76 703	34 608	100 244	158 171
	TOTAL	25 380	65 336	98 498	3 182	7 373	10 053	27 380	65 428	94 627	62 216	146 281	211 576
SOUTHERN EUROPE	≤10m	7 800	11 257	12 820	813	1 065	1 144	7 120	9 362	10 016	18 583	25 752	28 280
	>10m	64 599	148 012	210 553	4 854	9 763	11 738	67 852	163 889	235 417	140 564	325 749	462 057
	TOTAL	72 399	159 268	223 373	5 667	10 828	12 883	74 972	173 250	245 433	159 147	351 502	490 337
EASTERN EUROPE	≤10m	5 700	10 592	14 807	284	516	662	54 172	71 221	79 697	187 303	284 795	330 654
	>10m	12 283	42 284	74 590	680	1 805	2 572	244 629	680 683	1 079 815	461 732	1 203 701	1 867 421
	TOTAL	17 983	52 876	89 397	964	2 320	3 234	298 801	751 904	1 159 512	649 035	1 488 496	2 198 075

Annex Table 2. Elements of Shared Socioeconomic Pathways (SSPs) (O'Neill et al 2015). Country groupings by fertility are based on Samir and Lutz (2014) and by income are defined by the World Bank at http://data.worldbank.org/about/country-and-lending-groups.

SSP Element	Sustainable World Pathway (SSP1)	Middle of the Road (SSP2)	Fragmented World/ Stalled Development (SSP3)	Inequality (SSP4)	Fossil-fuel Led Development (SSP5)
Demographics – Population (by age, sex, education)					
Growth	Relatively low	Medium	High for High and Low fertility countries; Low for Rich OECD countries	Relatively high	Relatively low
Fertility	Low for High and Low fertility countries; Medium for Rich OECD countries	Medium	High for High and Low fertility countries; Low for Rich OECD countries	High for High fertility countries; Low for Low fertility countries, Low for OECD countries	Low for High and low fertility countries; High for Rich-OECD countries
Mortality	Low	Medium	High	High for High fertility countries; Medium for Low fertility countries; Medium for OECD countries	Low
Migration	Medium	Medium	Not prescribed	Medium	High
Demographics – Urbanization					
Level	High	Medium	Low	High for High Fertility countries; High for Low fertility countries; Low for OECD countries	High
Type	Well managed	Continuation of historical patterns	Poorly managed	Mixed across and within cities	Better management overtime, some sprawl
Human Development					
Education	High	Medium	Low	High Fertility – very low/ uneven, Low Fertility – low/ uneven, OECD – medium, uneven	High
Health investments	High	Medium	Low	Unequal within regions, lower in Low Income Countries (LICs), medium in High Income Countries (HICs)	High
Access to health facilities, water and sanitation	High	Medium	Low	Unequal within regions, lower in LICs, medium in HICs	High
Equity	High	Medium	Low	Medium	HIgh
Social cohesion	High	Medium	Low	Low, stratified	HIgh
Societal participation	High	Medium	Low	Low	High
Economy & Lifestyle					
Per capita growth	High in LICs & MICs; medium in HICs	Medium, uneven	Slow	Low in LICs, medium in other countries	High
Inequality	Reduced across and within countries	Uneven moderate reductions across and within countries	High, especially across countries	High, especially within countries	Strongly reduced, especially across countries
Consumption & Diet	Low growth in material consumption, low-meat diets, first in HICs	Material-intensive consumption, medium meat consumption	Material-intensive consumption	Elites: high consumption lifestyles; Rest: low consumption, low mobility	Materialism, status consumption, tourism, mobility, meat-rich diets

SSP Element	Sustainable World Pathway (SSP1)	Middle of the Road (SSP2)	Fragmented World/ Stalled Development (SSP3)	Inequality (SSP4)	Fossil-fuel Led Development (SSP5)
Policies and institutions					
Environmental Policy	Improved management of local and global issues: tighter regulation of pollutants	Concern for local pollutants but only moderate success in implementation.	Low priority for environmental issues	Focus on local environment in Medium Income Countries (MICs), HICs; little attention to vulnerable areas or global issues.	Focus on local environment with benefits to well-being, little concern with global problems
Policy orientation	Toward sustainable development	Weak focus on sustainability	Oriented toward security	For the benefit of the political and business elite	Toward development, free markets, human capital
Institutions	Effective at national & international levels	Uneven modest effectiveness	Weak global institutions/ national governments dominate societal decision making	Effective for political and business elite, not for the rest of society	Increasingly effective, oriented toward fostering competitive markets
Environment & Natural Resources					
Fossil constraints	Preferences shift away from fossil fuels	No reluctance to use unconventional resources	Unconventional resources for domestic supply	Anticipation of constraints drives up prices with high volatility	None
Environment	Improving conditions over time	Continued degradation	Serious degradation	Highly managed and improved near high/middle-income living areas, degraded otherwise.	Highly engineered approaches, successful management of local issues
Land Use	Strong regulations to avoid environmental tradeoffs	Medium regulations lead to slow decline in the rate of deforestation	Hardly any regulation; continued deforestation due to competition over land	Highly regulated in MICs, HICs; largely unmanaged in LICs leading to tropical deforestation	Medium regulation lead to slow decline in deforestation rate
Agriculture	Improvements in agricultural productivity; rapid diffusion of best practices	Medium pace of technological change in agricultural sector; entry barriers to agricultural markets reduced slowly	Low technology development, restricted trade	Agricultural productivity high for large scale industrial farming, low for small-scale farming	Highly managed, resource-intensive; rapid increase in productivity
Technology					
Development	Rapid	Medium, uneven	Slow	Rapid in high-tech economies and sectors; slow in others.	Rapid
Transfer	Rapid	Slow	Slow	Little transfer within countries to poorer populations	Rapid
Energy tech change	Directed away from fossil fuels, toward efficiency and renewables	Some investment in renewables but continued reliance on fossil fuels	Slow tech change, directed toward domestic energy sources	Diversified investments including efficiency and low-carbon sources	Directed toward fossil fuels; alternative sources not actively pursued
Carbon intensity	Low	Uneven, higher in Least Industrialized Countries (LICs)	High in regions with large domestic fossil fuel resources	Low/medium	High

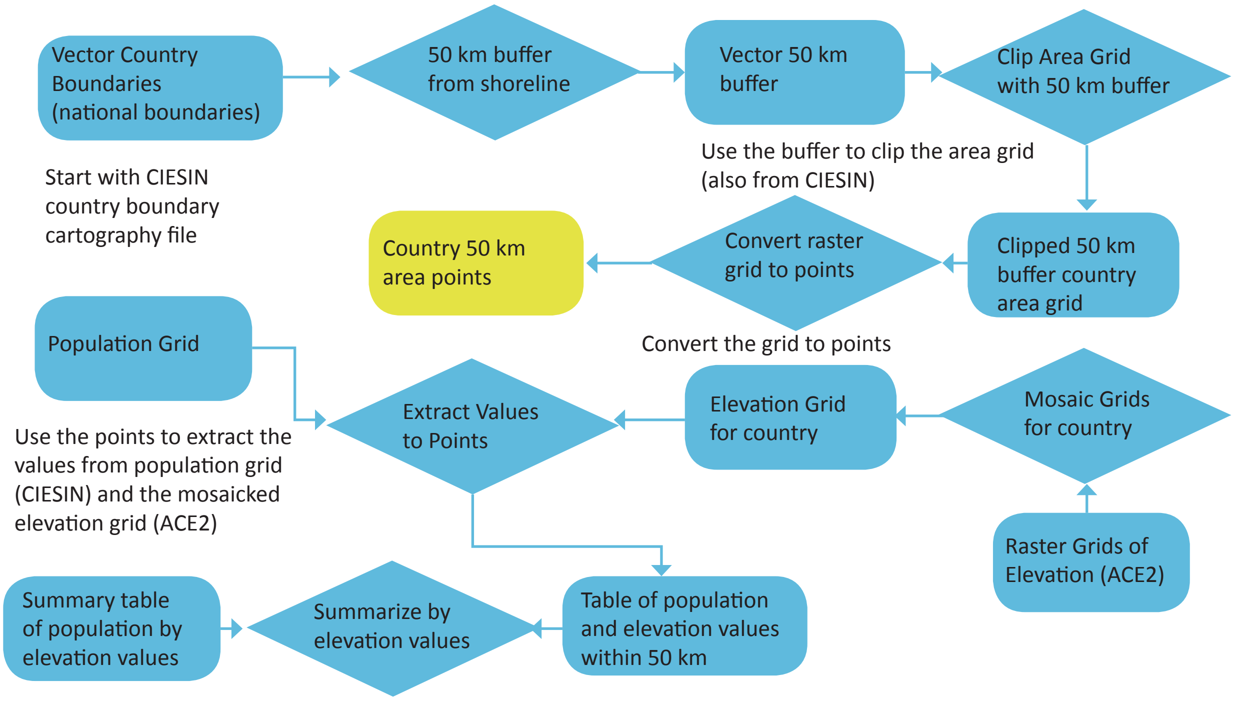
Annex Table 3. Coastal countries and their mean ranks for hazard (over RCP4.5 and RCP8.5), exposure (over 5 scenarios), vulnerability (over 5 scenarios), and SLR Risk Index (over 5 scenarios). For each metric, the top quintile is assigned very high risk (in red); second quintile is at high risk (in orange); third quintile is at moderate risk (in yellow); fourth quintile is at low risk (in green), and the last quintile is at very low risk (in blue). The countries are finally sorted from highest to lowest risk to SLR. The influence of vulnerability on SLR risk is most pronounced.

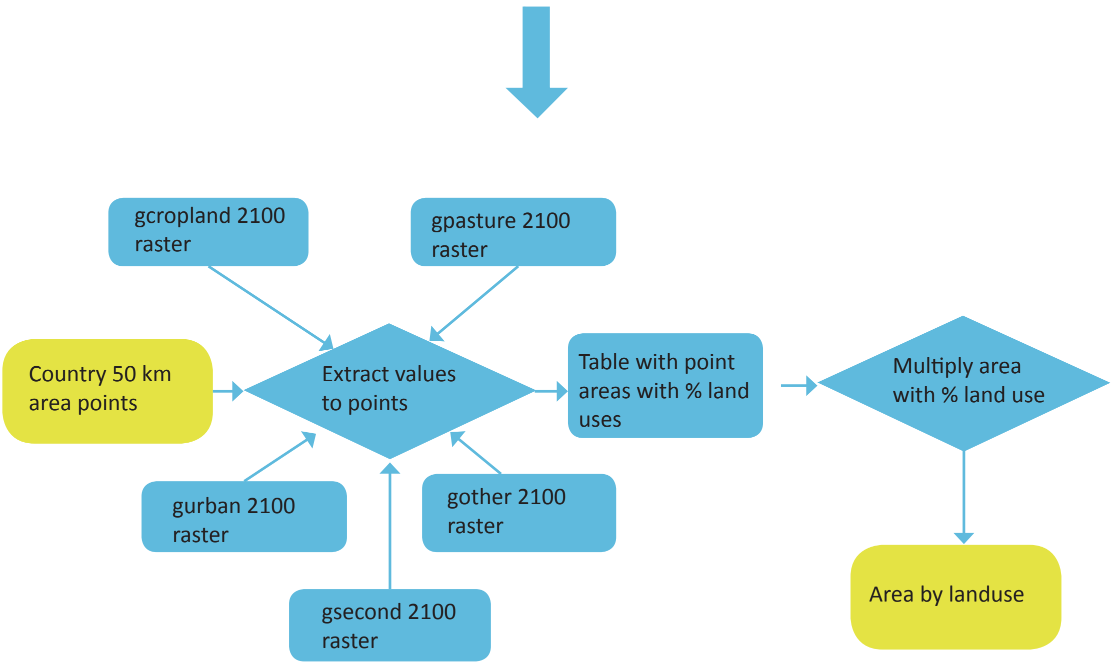
Country	Average hazard rank	Average exposure rank	Average vulnerability rank	Average slr risk rank	Country	Average hazard rank	Average exposure rank	Average vulnerability rank	Average slr risk rank
Somalia	19	66	1	1	Philippines	27	12	62	36
Mozambique	4	19	2	2	Sudan	112	82	18	37
Madagascar	9	29	5	3	Honduras	62	66	40	38
Angola	19	21	11	4	China	58	3	75	39
Liberia	60	42	4	5	Russian Federation	3	14	78	40
Sierra Leone	58	43	3	6	Djibouti	102	107	15	41
Papua New Guinea	19	37	9	7	Guatemala	86	94	30	42
Senegal	71	25	16	8	Haiti	77	83	38	43
Guinea-Bissau	67	56	6	9	Guyana	65	64	47	44
Mauritania	82	31	13	10	United States of America	1	1	111	45
Tanzania United Rep	60	34	19	11	Sri Lanka	53	33	58	46
Benin	50	55	10	12	Suriname	57	49	54	47
Myanmar	89	15	24	13	Nicaragua	28	86	50	48
Guinea	76	41	20	14	Namibia	22	110	36	49
Nigeria	41	7	43	15	Belize	64	78	48	50
India	44	4	45	16	Morocco	84	53	55	51
Togo	33	93	14	17	Thailand	49	17	80	52
Yemen	46	58	22	17	Timor-Leste	12	118	29	53
Congo Dem	28	99	12	19	Equatorial Guinea	17	117	33	54
Cameroon	50	68	26	20	Comoros	41	122	21	55
Solomon Islands	16	103	7	21	Mexico	24	13	101	56
Indonesia	11	2	61	22	Bahamas	14	69	70	57
Ghana	40	51	31	23	Cuba	15	44	77	58
Pakistan	120	28	23	24	Venezuela (Bolivarian Republic of)	52	26	82	59
Gabon	25	35	41	25	Egypt	103	9	81	60
Congo REP	37	59	31	26	Sao Tome and Principe	17	128	17	61
Viet Nam	62	6	49	27	Fiji	32	116	44	62
Eritrea	104	91	8	28	Colombia	36	36	86	63
Cambodia	87	76	27	29	Turkey	108	47	65	64
Bangladesh	113	8	42	30	Vanuatu	26	121	39	65
Gambia	75	72	24	31	Argentina	95	23	91	66
Brazil	33	5	57	32	Cape Verde	47	119	35	66
Côte d`Ivoire	54	51	37	33	Italy	98	30	92	68
South Africa	4	100	34	34	Netherlands	72	20	108	69
Kenya	35	84	28	35	Costa Rica	92	87	66	70
Maldives	30	114	53	71	Germany	80	27	127	106
Iraq	123	70	69	72	Bahrain	120	88	103	107
El Salvador	90	104	63	73	Samoa	31	127	59	108

Table (contd.)

Country	Average hazard rank	Average exposure rank	Average vulnerability rank	Average slr risk rank	Country	Average hazard rank	Average exposure rank	Average vulnerability rank	Average slr risk rank
Dominican Republic	70	79	85	73	Tunisia	105	65	117	109
Mauritius	10	124	45	75	Japan	6	16	137	110
Portugal	82	89	73	76	New Caledonia	12	109	115	111
Denmark	100	39	97	77	Syrian Arab Republic	119	125	55	112
Libyan Arab Jamahiriya	108	50	88	78	Sweden	133	45	120	113
Uruguay	94	81	76	79	Croatia	128	119	82	114
Ecuador	77	48	95	80	Belgium	97	92	121	115
Trinidad and Tobago	66	111	59	80	Barbados	56	133	51	116
Albania	118	102	52	80	Puerto Rico	54	106	130	117
Spain	68	45	104	83	Norway	129	63	124	118
Iran (Islamic Republic of)	115	40	93	84	Singapore	79	96	133	119
Jamaica	44	113	71	85	Aruba	37	128	100	120
United Kingdom of Great Britain and Northern Ireland	91	22	114	86	Korea Rep	69	57	138	121
Australia	7	10	127	87	Latvia	136	80	123	122
Oman	88	95	90	87	Lebanon	115	123	115	122
Algeria	111	90	74	89	Cyprus	107	115	124	124
Canada	2	17	134	90	Ireland	105	85	135	125
Peru	93	60	105	91	Saint Vincent and the Grenadines	43	136	68	126
Brunei Darussalam	74	105	87	91	Estonia	137	98	109	127
Malaysia	39	11	129	93	Montenegro	125	132	66	128
Poland	129	73	84	94	Lithuania	135	108	126	129
Israel	117	101	78	94	Saint Lucia	48	135	89	130
Qatar	127	71	94	96	Slovenia	124	131	95	131
New Zealand	7	62	121	97	Occupied Palestinian Territory	122	134	98	132
Chile	110	61	110	98	Finland	139	53	112	133
Greece	98	75	106	99	Hong Kong Special Administrative Region of China	80	112	138	134
France	100	32	118	100	Macao Special Administrative Region of China	84	130	131	135
Saudi Arabia	114	24	119	100	Iceland	138	97	131	136
Panama	73	77	113	102	Malta	95	137	136	137
Kuwait	125	74	99	103	Jordan	129	138	107	137
Tonga	23	126	64	104	Bosnia and Herzegovina	129	139	72	139

Annex Figure 1. GIS Methods for analyzing spatial data





Use the country 50 km area points from top flowchart. Use these points to extract the values from land use raster data. Each of the area points will have the % of landuse type. Multiply the % of landuse type by area to get area by land use.

1. For countries with no permafrost within 50 km from shore, we reallocated "iced areas" to other land uses, using **Equation 1:**

   [grid code]*(([specific land use 2100] + ([specific land use 2100] / [total land use area %]) * [ice %])) = new specific land use area

   Where:

   grid code = area for the grid
   total land use area % =% cropland 2100 + % urban2100 +% pasture 2100 + %secondary2100 + % others 2100

   ice % = 1 – total land use area %
2. For countries with permafrost:
   a. We extracted values from the regional permafrost maps from the Global Geocryological Data System, University of Colorado National Snow and ice Data Center (Table 4), assigning 100% of area for delineated permafrost areas
   b. We extracted the values for the remaining areas for cropland, urban, pastureland, secondary land, and other land uses using **Equation 1**

3. To determine freshwater systems within the 50 km coast:
   a. We extracted values from the Global Lakes and Wetlands Database GLWD3.0 Layer (Lehner and Doll 2004) (Table 4), assigning 100% of area for freshwater bodies.
   b. We extracted the values for the remaining areas for cropland, urban, pastureland, secondary land, and other land uses using **Equation 1,** replacing ice% with wetlands% in **Equation 1.**

Coral reef at palmyra atoll national wildlife refuge

Annex Table 4. Countries commonly populated with modelled data for the SSP scenarios reached 143 in number. Of these, countries surrounding the Black Sea, Bulgaria, Georgia, Romania and Ukraine, do not have IPCC projected data for sea level change, so that only 139 countries were assessed for sea level change associated risk.

SSP COUNTRY	Region	SSP COUNTRY	Region
Algeria	North Africa	Bahrain	Western Asia
Egypt	North Africa	Cyprus	Western Asia
Libyan Arab Jamahiriya	North Africa	Iran (Islamic Republic of)	Western Asia
Morocco	North Africa	Iraq	Western Asia
Sudan	North Africa	Israel	Western Asia
Tunisia	North Africa	Jordan	Western Asia
Benin	Western Africa	Kuwait	Western Asia
Cape Verde	Western Africa	Lebanon	Western Asia
Côte d`Ivoire	Western Africa	Occupied Palestinian Territory	Western Asia
Gambia	Western Africa	Oman	Western Asia
Ghana	Western Africa	Qatar	Western Asia
Guinea	Western Africa	Saudi Arabia	Western Asia
Guinea-Bissau	Western Africa	Syrian Arab Republic	Western Asia
Liberia	Western Africa	Turkey	Western Asia
Mauritania	Western Africa	United Arab Emirates	Western Asia
Nigeria	Western Africa	Yemen	Western Asia
Senegal	Western Africa	Bangladesh	Southern Asia
Sierra Leone	Western Africa	India	Southern Asia
Togo	Western Africa	Maldives	Southern Asia
Angola	Middle Africa	Pakistan	Southern Asia
Cameroon	Middle Africa	Sri Lanka	Southern Asia
Congo, Democratic Republic of	Middle Africa	Brunei Darussalam	Southeastern Asia
Congo, Republic of	Middle Africa	Cambodia	Southeastern Asia
Equatorial Guinea	Middle Africa	Indonesia	Southeastern Asia
Gabon	Middle Africa	Malaysia	Southeastern Asia
Sao Tome and Principe	Middle Africa	Myanmar	Southeastern Asia
Namibia	Eastern Africa	Philippines	Southeastern Asia
South Africa	Eastern Africa	Singapore	Southeastern Asia
Comoros	Eastern Africa	Thailand	Southeastern Asia
Djibouti	Eastern Africa	Timor-Leste	Southeastern Asia
Eritrea	Eastern Africa	Viet Nam	Southeastern Asia
Kenya	Eastern Africa	China	Eastern Asia
Madagascar	Eastern Africa	Hong Kong Special Administrative Region of China	Eastern Asia
Mauritius	Eastern Africa	Japan	Eastern Asia
Mozambique	Eastern Africa	Korea, Republic of	Eastern Asia
Somalia	Eastern Africa	Macao Special Administrative Region of China	Eastern Asia
Tanzania, United Republic of	Eastern Africa		
Australia	Oceania	Denmark	Northern Europe

SSP COUNTRY	Region	SSP COUNTRY	Region
New Zealand	Oceania	Estonia	Northern Europe
Fiji	Oceania	Finland	Northern Europe
New Caledonia	Oceania	Iceland	Northern Europe
Papua New Guinea	Oceania	Ireland	Northern Europe
Solomon Islands	Oceania	Latvia	Northern Europe
Vanuatu	Oceania	Lithuania	Northern Europe
Samoa	Oceania	Norway	Northern Europe
Tonga	Oceania	Sweden	Northern Europe
Canada	Northern America	United Kingdom of Great Britain and Northern Ireland	Northern Europe
United States of America	Northern America	Belgium	Western Europe
Belize	Central America	France	Western Europe
Costa Rica	Central America	Germany	Western Europe
El Salvador	Central America	Netherlands	Western Europe
Guatemala	Central America	Albania	Southern Europe
Honduras	Central America	Bosnia and Herzegovina	Southern Europe
Mexico	Central America	Croatia	Southern Europe
Nicaragua	Central America	Greece	Southern Europe
Panama	Central America	Italy	Southern Europe
Argentina	Southern America	Malta	Southern Europe
Brazil	Southern America	Montenegro	Southern Europe
Chile	Southern America	Portugal	Southern Europe
Colombia	Southern America	Slovenia	Southern Europe
Ecuador	Southern America	Spain	Southern Europe
Guyana	Southern America	Poland	Eastern Europe
Peru	Southern America	Russian Federation	Eastern Europe
Suriname	Southern America		
Uruguay	Southern America		
Venezuela (Bolivarian Republic of)	Southern America		
Aruba	Caribbean		
Bahamas	Caribbean		
Barbados	Caribbean		
Cuba	Caribbean		
Dominican Republic	Caribbean		
Haiti	Caribbean		
Jamaica	Caribbean		
Puerto Rico	Caribbean		
Saint Lucia	Caribbean		
Saint Vincent and the Grenadines	Caribbean		
Trinidad and Tobago	Caribbean