ADAPTATION POLICY FOR A SUSTAINABLE COASTAL FUTURE

Insights from the RISES-AM project

180cm SEA-LEVEL RISE

OR MORE BY 2100

UNDER HIGH-END SCENARIOS

UP TO US$ 50 TRILLION

ANNUAL SEA-FLOOD DAMAGE BY 2100

IF NO ADAPTATIONS MEASURES ARE TAKEN

COASTAL WETLAND AREAS

ARE LIKELY TO GROW

IF ONLY URBAN AREAS ARE PROTECTED THROUGH HARD MEASURES

ADAPTATION

IS POSSIBLE, EFFECTIVE & AFFORDABLE

IMPACTS CAN BE REDUCED BY UP TO 99.9 PERCENT

BARRIERS

SOCIAL & INSTITUTIONAL FACTORS

CONSTITUTE THE MAIN BARRIERS FOR THE IMPLEMENTATION OF ADAPTATION MEASURES

RISES-AM-
EU Research Project

RISES-AM has assessed the impacts of future sea-level rise and the effectiveness of adaptation options and strategies.

RISES-AM PROJECT

This briefing note presents results of the RISES-AM project, which has assessed the impacts of future sea-level rise and the effectiveness of adaptation options and strategies. The project has also considered the barriers to implementing adaptation at local, regional and global scales, across a range of representative concentration pathways (RCPs) and shared socio-economic pathways (SSPs), including exploring high-end scenarios not included in IPCC reports.

High-end scenarios may refer to climate change drivers of coastal impacts (such as e.g. sea level rise) or to socio-economic drivers affecting exposure and vulnerabilities (e.g. assets or population affected). In RISES-AM- we have considered such high-end scenarios from short (months) to long (decades) time scales. The analysis is centred around scenario RCP 4.5 and goes up to 2100 but also a new high-end sea-level rise scenario developed within RISES-AM. High-end scenarios are particularly important for the management of situations of high exposure and risk aversion, which is generally the case for many densely populated coastal zones.

RISES-AM assessed impacts both under present adaptation practice (business as usual) as well as under "additional" adaptation that will be required due to the expected acceleration of climate change during this century. For the latter we have sequentially structured the possible adaptation interventions into adaptation pathways that prevent decisions conflicting with longer term limits or requirements. The emphasis has been on vulnerable coastal systems such as deltas or low-lying coastal areas with large population. The results obtained present a significant opportunity for contributing to current and future policy making, because they take into account the possibility of high-end sea-level rise, resulting from the lag between emissions and equilibrium sea-levels as well as insufficient climate change mitigation.

INFOBOX

WHAT ARE RCPS AND SSPS?

Socio-economic and emission scenarios are used in climate research to provide plausible descriptions of how the future may evolve with respect to a range of variables including socio-economic change, technological change, energy and land use, and emissions of greenhouse gases. The new scenario framework for climate change research combines pathways of future radiative forcing (Representative Concentration Pathways) and their associated climate changes with alternative pathways of socioeconomic development (Shared Socioeconomic Pathways) in order to carry out research on climate change impacts, adaptation, and mitigation.

Representative Concentration Pathways (eg. RCP 4.5, RCP8.5)

The RCPs are a set of four pathways that lead to radiative forcing levels of 2.6, 4.5, 6 and 8.5 W/m2, by the end of the century. They represent the range of forcing levels covered in the literature and contain relevant information for climate model runs, such as emission, concentration and land-use trajectories.

Shared Socio-Economic Pathways (eg. SSP3 or SSP5)

The SSPs describe possible pathways for society and society-influenced systems to develop in the course of the 21st century. They have been developed on global to regional scales based on socio-economic challenges for mitigation and adaptation. SSP1 describes a sustainable world with low challenges; SSP2 is a 'Middle of the Road' pathway; SSP3 assumes regional rivalry with high challenges for both, mitigation and adaptation. SSP4, is characterised by inequality and high challenges for adaptation; SSP5 is the pathway of fossil-fuelled development and has high challenges for mitigation. The highest Gross Domestic Product (GDP) and lowest population GDP and population are attained under SSP1 and SSP5. GDP is lowest and population highest under SSP 3 and a similar but less extreme trend is followed under SSP 4. SSP 2 reflects a world with medium assumptions between the other four SSPs.

Within the new scenario framework, individual SSPs can be combined with different RCPs in order to construct climate change scenarios for the 21st century.

SEA LEVELS MAY RISE SUBSTANTIALLY ABOVE THOSE PROJECTED BY THE IPCC.

The uncertainties ranges associated with sea-level projections are larger than those associated with temperature projections and also larger than those presented in the latest Assessment Report of the IPCC (AR5).

AR5 found that there is an at least 66% chance that global mean sea-level will rise by 28-98 cm until 2100 under all greenhouse gas concentration scenarios considered (Church et al., 2013). This, however, means that there is a high probability (up to 34%) that sea-level rise (SLR) may lie outside of this range and the management of high-risk coastal areas needs to consider this (Hinkel et al. 2015). These high uncertainties are mainly due to the current deficits of ice sheet models' ability to reliably assess the contribution of the melting of the Greenland and Antarctica ice sheets to sea-level rise.

RISES-AM has addressed this issue and developed new high-end scenarios based on RCP8.5 projections and available expert judgement for the contributions of Greenland and Antarctica ice sheet melting to SLR instead of ice sheet models (Jevrejeva et al., 2014). According to these results, there is a 95% chance that global mean SLR will stay below 180cm by the end of 21st century under the highest greenhouse gas emission scenario RCP8.5 (see Figure 1). Higher SLR cannot be excluded, but is very unlikely.

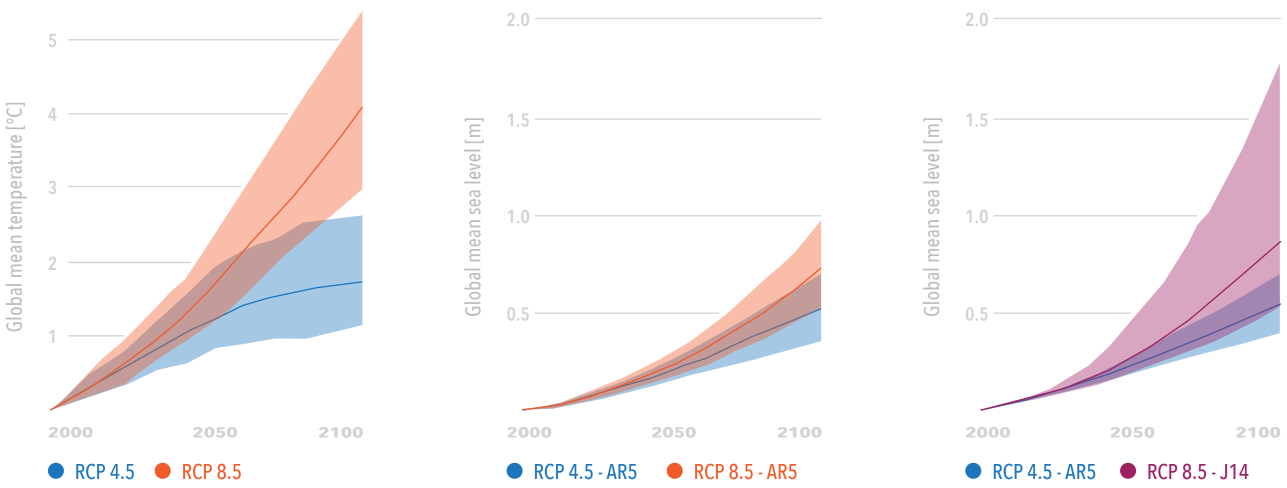
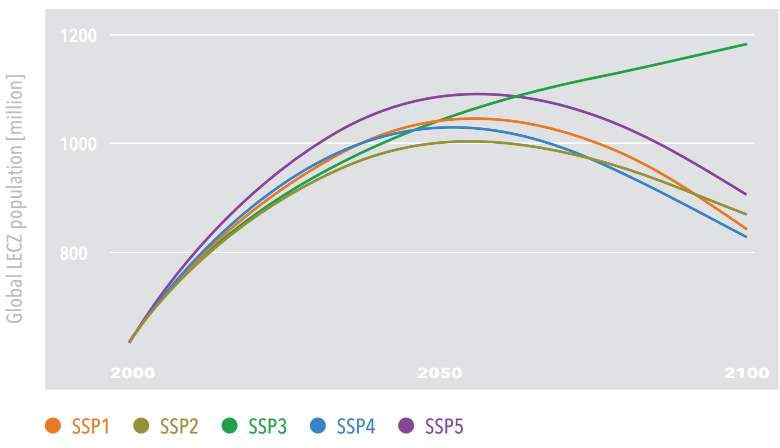


Figure 1: Global mean temperature change as reported in AR5 (left), global mean sea-level change as reported in AR5 (middle) and the high-end sea-level rise scenarios (RCP 8.5 – J14) produced in the RISES-AM project (right). All values are relative to 1986-2005. The shaded areas show the 5-95% uncertainty range.

COASTAL IMPACTS WILL NOT ONLY DEPEND ON SEA-LEVEL RISE BUT WILL ALSO BE STRONGLY INFLUENCED BY SOCIO-ECONOMIC DEVELOPMENT.

Coastal zones are already risky areas suffering from a range of human pressures, which are expected to further grow in the next decades.



The Low Elevation Coastal Zone (LECZ), which covers all areas below 10m above mean sea-level, constitutes 2% of world's land area but contains 10% of world's population (600 million people globally) based on estimates from 2000 (McGranahan et al., 2007). About 65% of the world's cities with populations of over 5 million are located in the LECZ (McGranahan et al., 2007). This population is growing rapidly due to coastal urbanisation and is expected to exceed 1 billion in 2050 under every socio-economic scenario (Merkens et al. 2016).

Growing populations exert a range of direct pressures on coastal areas in terms of changes in land use and land subsidence, which adds to climate induced sea-level rise. Moreover, catchment management is having profound effects on water and nutrients, in particular reducing sediment inputs to the coastal zone. Losses in coastal areas can be expected to continue and are likely to become larger, due solely to the increasing population. To be successful, an adaptation agenda for coastal zones needs to address these challenges as well as those arising from climate change.

THE MAIN IMPACTS OF SEA-LEVEL RISE OCCUR DUE TO EXTREME SEA-LEVEL EVENTS AND COASTAL ZONES ARE ALREADY AT RISK FROM SUCH EXTREME EVENTS TODAY.

Impacts of sea-level rise on human settlements primarily occur via extreme sea-level events rather than as a direct consequence of mean sea-level rise (Wong et al. 2014). Extreme sea-levels occur during storms due to wind- and pressure-induced storm surges, potentially causing serious flooding as illustrated by Hurricane Sandy in New York in 2012) and Typhoon Haiyan in the Philippines in 2013). Under current conditions, on average 11 million people are subject to flooding annually (Muis et al., in review) with annual average sea flood costs of around US$ 11–40 billion per year (Hinkel et al. 2014). To better understand current and future risks, RISES-AM has developed the Global Tide and Surge Reanalysis (GTSR) dataset (Muis et al., 2016), which is the first global dataset of extreme sea-levels based on hydrodynamic modelling. The dataset provides estimates for various return periods. Figure 2 shows the height of the 100-year return period for present day conditions

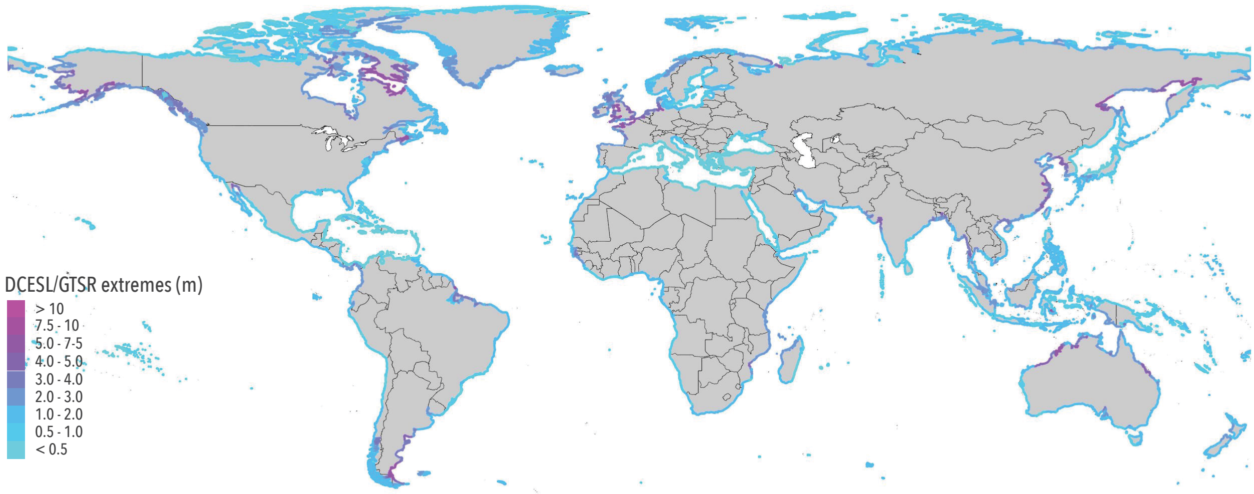


Figure 2: Extreme sea levels with a 100-year return period (present day conditions).

IF NO ADAPTATION MEASURES ARE TAKEN, GLOBAL IMPACTS OF SEA-LEVEL RISE ON HUMAN SETTLEMENTS WILL BE DISASTROUS. AT THE SAME TIME, PROTECTING COASTAL URBAN AREAS IS VERY EFFECTIVE AND COST-EFFICIENT IN REDUCING IMPACTS.

RISES-AM used the new high-end sea-level rise scenarios and the new extreme sea-level database for improving global estimates of sea-level rise impacts on human settlements. Following business-as-usual coastal zone management and (i.e. ignoring sea-level rise) could result in up to US$ 50 trillion in annual flood damage under the high-end scenario (RCP 8.5 – J14). Adapting to sea-level rise by building and raising defenses can reduce the total cost (damage and adaptation cost) by 1 to 3 orders of magnitude (Figure 3). Our results show further that for 12% of the world's coastline it is economically robust to protect, i.e. protecting is cheaper than not protecting under all plausible combinations of sea-level rise and socio-economic scenarios (Lincke and Hinkel, in preparation). These 12% of coastline account for 89% of global coastal floodplain population and 94 % of assets in the global coastal floodplain.

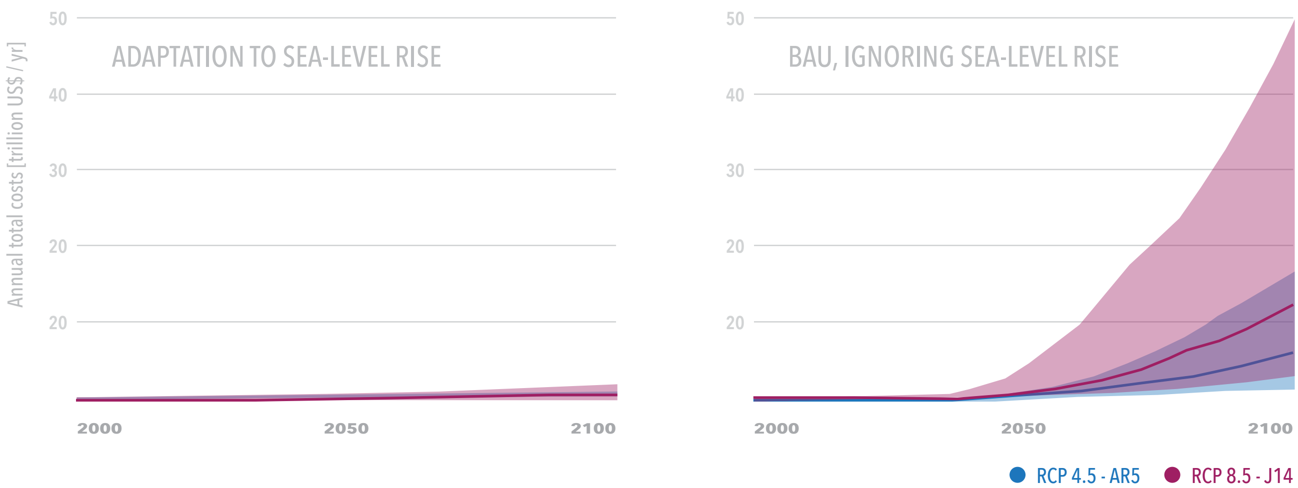


Figure 3: Global annual total cost of sea-level rise (protection cost and damage cost) under RCP 4.5 - AR5 and RISES-AM high end sea-level rise (RCP8.5 - J14) with adaptation (left) and without adaptation (right). The shaded areas show the 5-95% uncertainty range.

THERE ARE SIGNIFICANT TRADE-OFFS BETWEEN PROTECTING COASTS THROUGH HARD PROTECTION MEASURES AND MAINTAINING GLOBAL WETLANDS.

RISES-AM developed a state-of-the-art model of global wetland change and applied it under the high end sea-level rise scenario (RCP 8.5 – J14). Our results show that the main driver for wetland loss is the construction of hard coastal protection (e.g. dikes, sea-walls, etc.) and other infrastructure rather than sea-level rise. When assuming that the whole global coastline would be protected against sea-level rise through hard measures, 85% of global wetland areas will be lost until 2100 compared to today. If, however, only coastlines with a population density exceeding 30 people/km² (about 39% of the global coastline) are protected by hard defences (reflecting business as usual), coastal wetlands areas will increase by 28% compared with 2015 under the high-end scenario of 180 cm by 2100 (RCP 8.5 – J14). This result is due to wetlands' ability to vertically grow with increasing rates of sea-level rise if both accommodation space and sufficient sediment are available. If only urban areas with a population density exceeding 1000 people/km² (about 12% of the global coastline) are protected by hard defences, wetlands would grow by 44% compared with 2015.

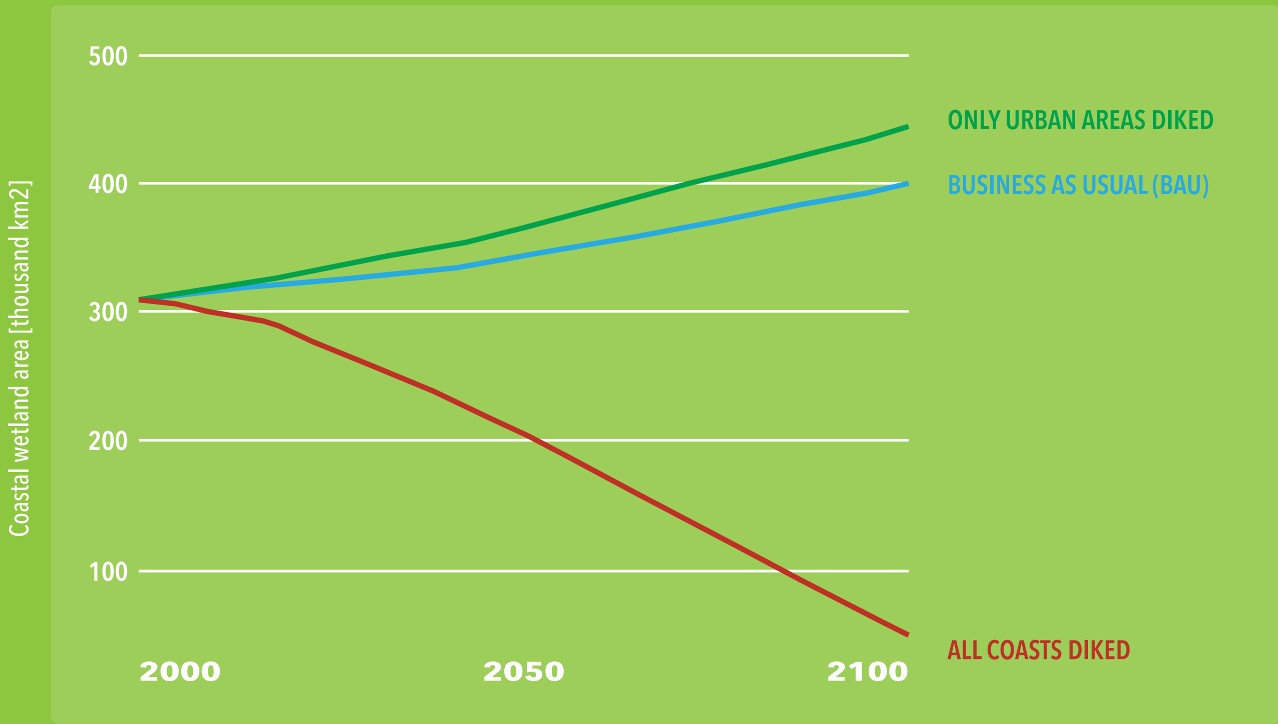


Figure 4: Projected change in global wetland area under three different protection strategies for the high end SLR scenario (RCP8.5 - J14) and a global population growth according to SSP5.

A RANGE OF INNOVATIVE/GREEN ADAPTATION MEASURES ARE AVAILABLE AND MIGHT BE BETTER SUITED THAN HARD MEASURES TO ADDRESS HIGH-END SEA-LEVEL RISE.

The range of adaptation measures considered in RISES-AM includes traditional interventions but favours innovative adaptation measures aligned with natural processes. This is because traditional interventions (rigid, e.g., sea-walls or soft, e.g., artificial sand nourishment) are expected to become difficult to sustain under high-end climate scenarios. On the contrary, the generation of "room" for coastal dynamics as a natural solution to cope with varying wave conditions and rising sea-levels is easier to sustain in the long run due to less energy needs and costs associated to their implementation. Coastal wetlands, for example, are known to effectively attenuate storm wave and surge energy and may be created where enough accommodation space is available. Another example of such a nature-based approach is the re-introduction of natural water and sediment fluxes (often bypassing sediments trapped in reservoirs) into sediment-starved deltas to slow down coastal erosion and raise the ground level through vertical accretion. This combines local retreat to recover the back beach as a buffer for dissipating wave action and the generation of sand deposits with increased riverine fluxes in the lower course to enhance sediment transport and deposition towards the coast. Such nature-based coastal adaptation can only be achieved within a planned evolution of coastal land-uses (and associated infrastructure) that combines maintenance and retreat.

BARRIERS TO COASTAL ADAPTATION LIE MORE IN THE SOCIO-ECONOMIC REALM THAN IN THE TECHNICAL REALM.

RISES-AM analysed technological, economic, financial and social conflicts and barriers to coastal adaptation under high-end sea-level rise in a range of case studies at different scales (see Table 1). Across all cases, adaptation was found to be technologically possible. Generally, in the cases considered adaptation is costly but pays off in pure monetary terms for densely populated urban regions. We found very high benefit-cost ratios for protecting cities as well as for nourishing beaches used for tourism, which suggests that these two measures will be wide-spread in the future. In rural and poorer areas, however, protection measures generally have benefit-cost ratios smaller than one, which suggests that it will be difficult to mobilise the required resources for protection if those regions don't receive money from elsewhere.

CASE	ADAPTATION GOAL	OPTIONS CONSIDERED
Liverpool/Mersey	Reduce flood risk *in situ*	Tidal barrage, tidal lagoons
Danube delta	Maintain wetlands	Planting reeds, artificial reefs
Catalan coast	Maintain beaches and tourism	Beach nourishment
	Reduce erosion damage to land	Beach nourishment, artificial dunes, protection structures, managed retreat
	Reduce sea-level rise damage to ports	Break waters, covered with vegetation
Ebro delta	Maintain rice production	Dikes, land raising, segmentation of drainage and irrigation networks
Hamburg	Reduce flood risk *in situ*	Dikes, sea-walls, retention areas
Hulhumalé (Maldives)	Reduce flood risk *in situ*	Flood warning system, beach nourishment, sea-walls, pumps & drainage, land raising
Ho Chi Min City	Reduce flood risk *in situ*	Dike rings, land raising and flood-proofing buildings
Croatia	Reduce flood risk	Dikes, set-back zones
Aveiro coast (Portugal)	Maintain land threatened by erosion	Nourishment
Holland coast (The Netherlands)	Maintain land threatened by erosion	Nourishment
Global flood risk	Maintain land threatened by erosion	Dikes, managed retreat
Mediterranean	Reduce flood risk	Dikes, set-back zones, flood-proofing buildings
European Union flood risk	Reduce flood risk	Dikes

But even when coastal protection is attractive in monetary terms, mobilising financial resources may be difficult due to high up-front investments paired with long-term stochastic returns on investment. Irrespective of the technological, economic and financing situation, it was also found that most coastal adaptation options involve significant social conflicts due to diverse coastal stakeholders, interests, activities and policy goals (e.g., flood security, tourism, nature protection, shipping and ports). We conclude that integrating financial, equity and social conflict issues will be a key for advancing coastal adaptation.

TECHNOLOGICAL LIMITS	PROFITABILITY BARRIERS	FINANCING BARRIERS	SOCIAL CONFLICTS
no	yes	no	yes
no	some	yes	yes
no	no	no	no
no	yes	yes	yes
no	no	yes	yes
no	yes	yes	some
no	n/a	no	yes
no	no	no	yes
no	no	yes	yes
no	some	yes	yes
no	no	yes	no
no	no	no	no
no	no	some	yes
no	no	some	yes
no	no	some	yes

Table 1: Overview of coastal case studies, adaptation goals and options considered as well as the technological, economic, financial and institutional limits and social conflict barriers arising.

REFERENCES

Bamber, J.L., Aspinall, W.P., 2013. An expert judgement assessment of future sea level rise from the ice sheets. Nature Clim. Change 3, pp. 424–427. doi:10.1038/nclimate1778

Church, J.A., Clark, P.U., Cazenave, A., Gregory, J.M., Jevrejeva, S., Levermann, A., Merrifield, M.A., Milne, G.A., Nerem, R.S., Nunn, P.D., Payne, A.J., Pfeffer, W.T., Stammer, D., Unnikrishnan, A.S., 2013. Sea Level Change., in: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Hinkel, J., C. C. Jaeger, R. J. Nicholls, J. Lowe, O. Renn, S. Peijun, 2015. Sea-level rise scenarios and coastal risk management. Nature Climate Change 5. doi:101038/nclimate2505.

Hinkel, J., D. Lincke, A. T. Vafeidis, M. Perrette, R. J. Nicholls, R. S. J. Tol, B. Marzeion, X. Fettweis, C. Ionescu, A. Levermann, 2014. Coastal flood damage and adaptation cost under 21st century sea-level rise. Proceedings of the National Academy of Sciences 111(9), pp. 3292--3297. doi:10.1073/pnas.1222469111

Jevrejeva, S., Grinsted, A., Moore, J.C., 2014. Upper limit for sea level projections by 2100. Environ. Res. Lett. 9, 104008. doi:10.1088/1748-9326/9/10/104008

Lincke, D., Hinkel, J. in preparation. Robust coastal protection analysis under 21st century sea-level rise.

Merkens, J.-L., Reimann, L., Hinkel, J. and Vafeidis, A.T., 2016. Gridded population projections for the coastal zone under the Shared Socioeconomic Pathways. Global and Planetary Change, 145, 57–66.

Muis, S., Verlaan, M., Nicholls, R.J., Brown, S., Hinkel, J., Lincke, D., Vafeidis, A.T., Scussolini, P., Winsemius, H.C., Ward, P.J., in review, An intercomparison of two datasets of extreme sea levels and resulting global flood risk. Submitted to Earth's Future in August 2016.

Muis, S., Verlaan, M., Winsemius, H.C., Aerts, J.C.J.H., Ward, P.J., 2016. A global reanalysis of storm surge and extreme sea levels. Nature Communications 7, pp. 1–11. doi:10.1038/ncomms11969.

Wong, P.P., Losada, I.J., Gattuso, J.-P., Hinkel, J., Khattabi, A., McInnes, K.L., Saito, Y., Sallenger, A., 2014. Coastal systems and low-lying areas, in: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E.S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel of Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 361–409.

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