UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH
Escola Tècnica Superior d'Enginyeria
de Camins, Canals i Ports de Barcelona

Adaptating to climatic coastal impacts
…. with emphasis on SLR

José A. Jiménez

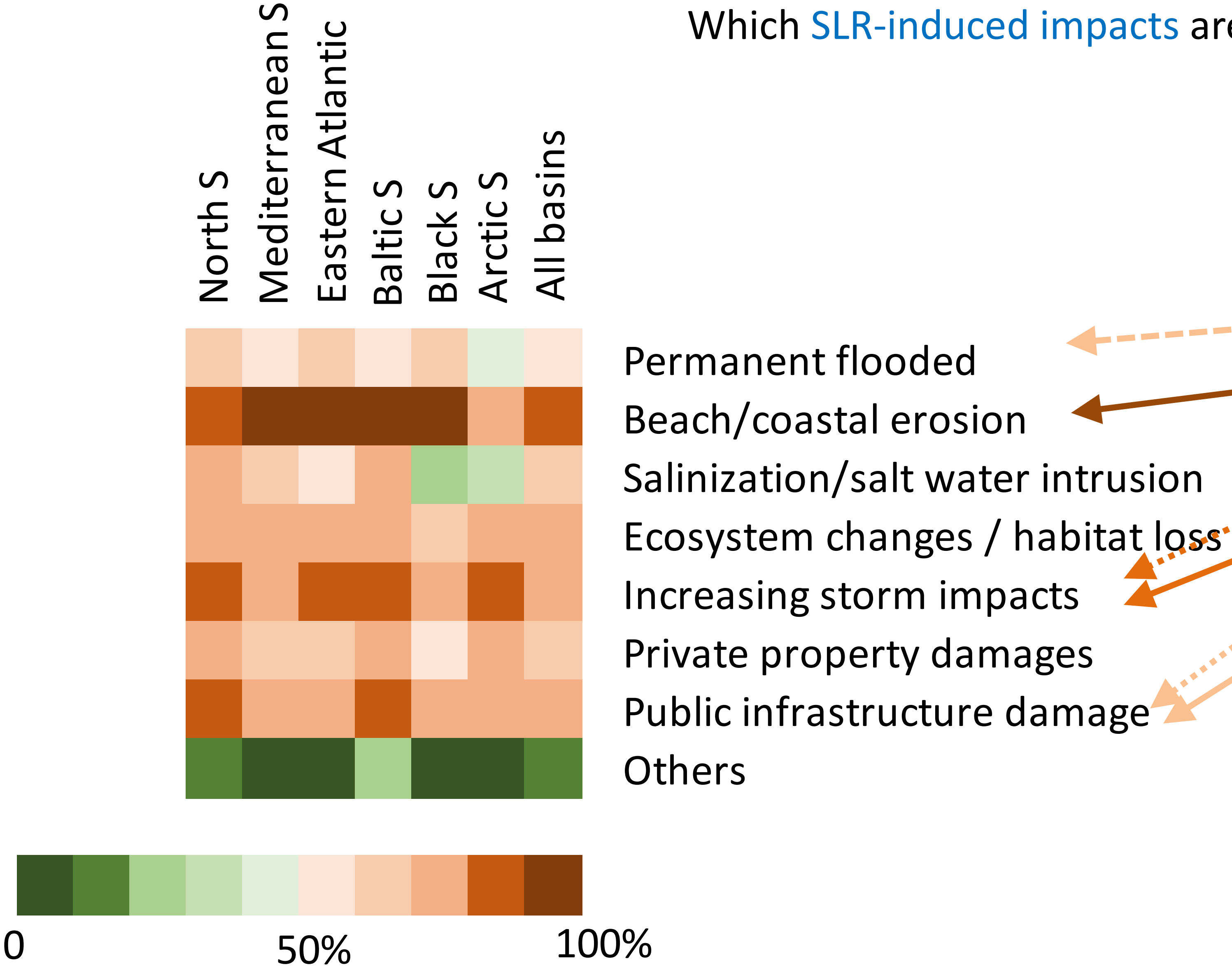
jose.jimenez@upc.edu

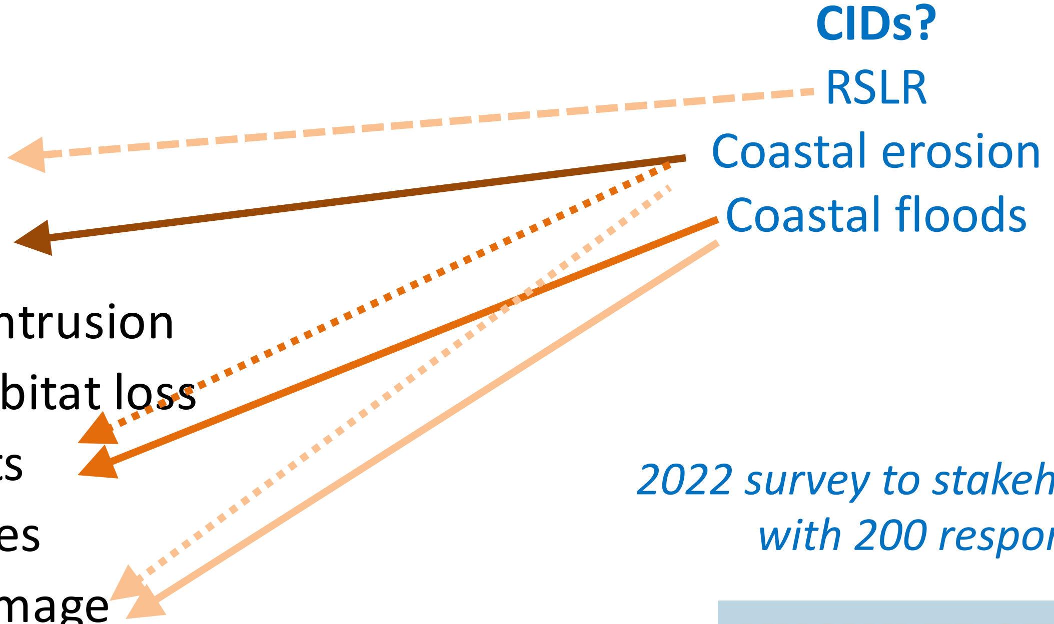
Laboratori d'Enginyeria Marítima
Universitat Politècnica de Catalunya·BarcelonaTech
Barcelona

CoastSpace TED2021-130001B-C21 (MCIN/AEI/10.13039/501100011033)

GOBIERNO DE ESPAÑA
MINISTERIO DE CIENCIA E INNOVACIÓN

Which SLR-induced impacts are relevant for your country/region?

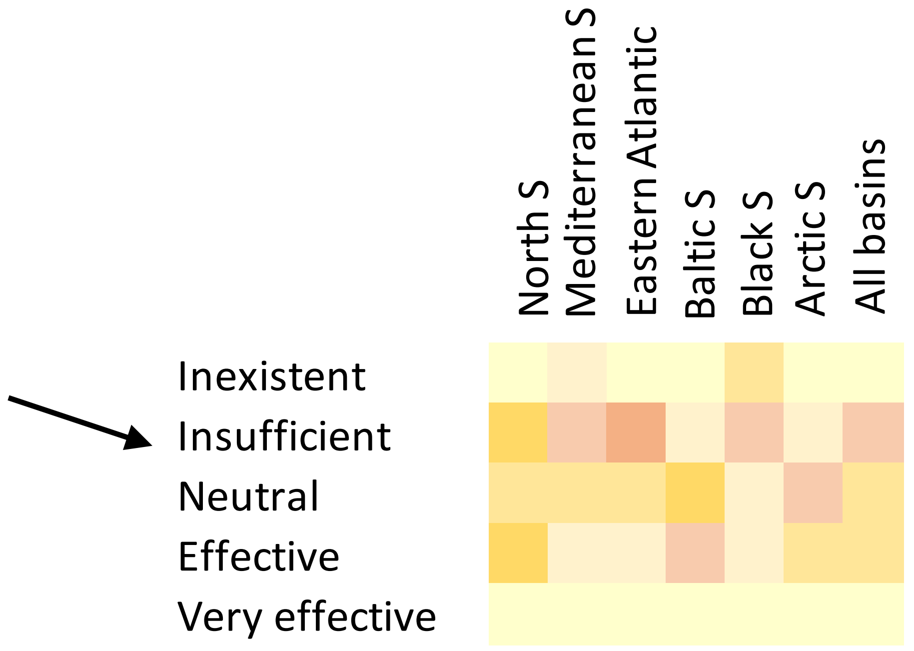




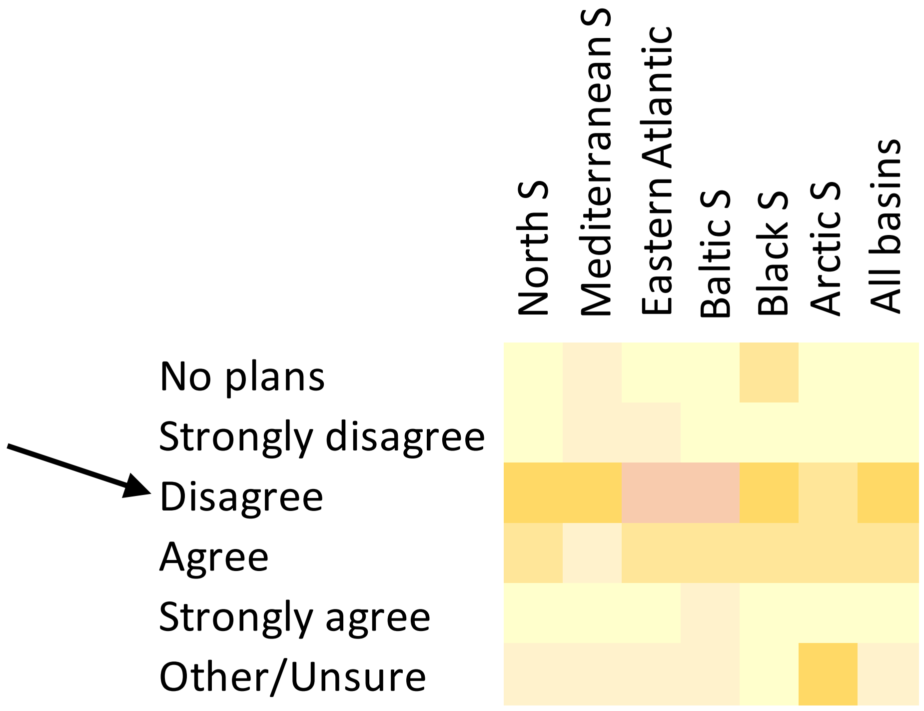
2022 survey to stakeholders with 200 respondents

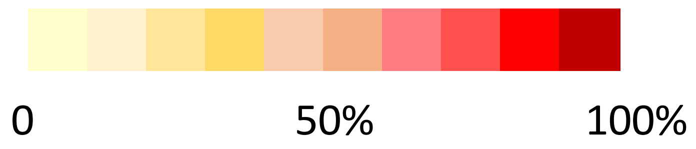
KNOWLEDGE HUB
SEA LEVEL RISE
A joint effort by
JPI Climate JPI OCEANS

How **effective** do you consider the present adaptation strategy to SLR in your country/region ?



Existing adaptation strategies/plans are **flexible** enough to adapt to future updates in SLR-induced impacts, or to cope with the inherent uncertainty in their assessment.





2022 survey to stakeholders with 200 respondents

KNOWLEDGE HUB
SEA LEVEL RISE
A joint effort by
JPI Climate JPI OCEANS

Coastal adaptation to sea-level rise refers to the process of **adjusting to** the impacts and potential risks associated with rising sea levels.

It involves **implementing strategies and measures** to address these impacts and risks by **enhancing resilience** and **reducing vulnerability** to SLR-induced hazards.

storm-induced coastal damage are frequent

sedimentary coastlines are already eroding

warning

Adaptation capacity and governance to manage risks from projected sea level rise **typically require decades to implement and institutionalise** (high confidence).

AR6 WGII IPCC

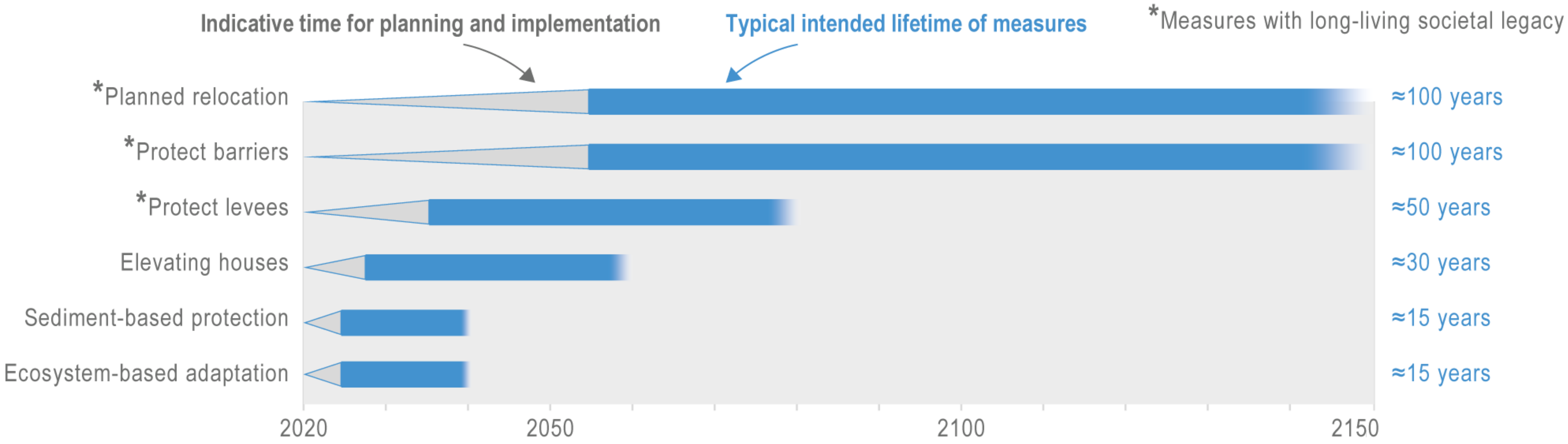
risks are getting worse →

While many might assume that the main resource need for adaptation is money, **time is the most evident declining resource.** Delays or inadequate action in the early stages can lead to increased costs in the future.

López-Doriga et al. (2020)

Sea level rise challenges the timing of coastal adaptation planning and implementation

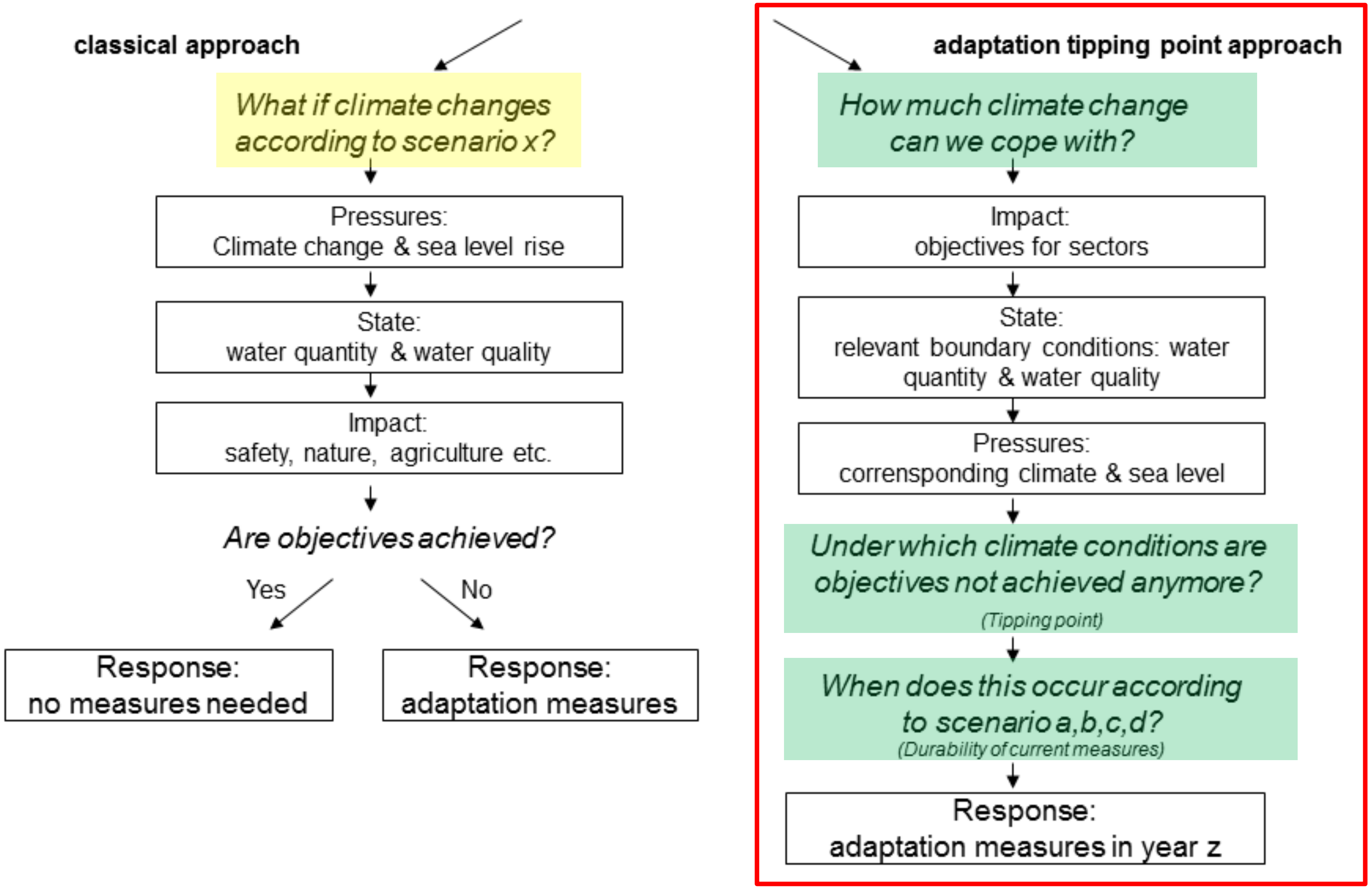
(a) Typical timescales of coastal risk management



The challenge of coastal adaptation in the era of sea level rise (SLR): typical time scales for the planning, implementation (grey triangles) and operational lifetime of current coastal risk-management measures (blue bars).

(AR6 WGII IPCC)

How vulnerable are we for climate change and sea level rise and what adaptation measures should we take ?



Classical **top-down approach** and **adaptation tipping point approach** to develop adaptation measures

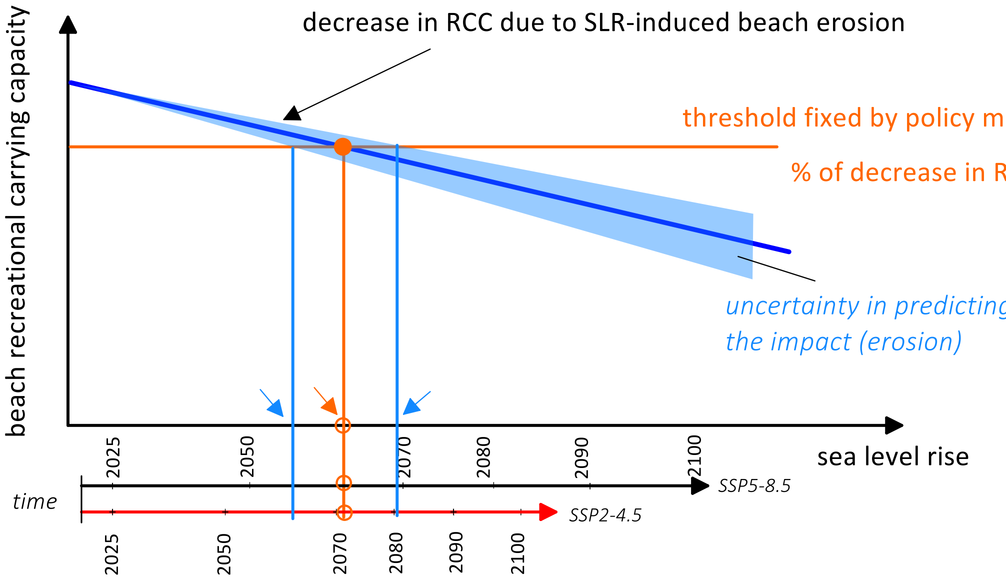
(Kwadijk et al 2010)

The concept (*challenge*) of Adaptation Tipping Point (ATP)

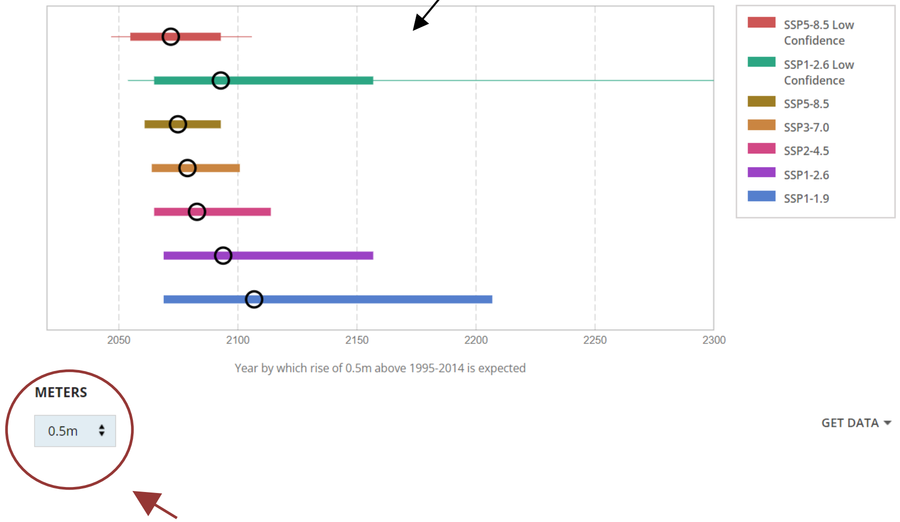
hazard X

ATP can be defined as the **threshold** at which the impacts of ***climate change (SLR)*** are such that the current management strategy (or status quo) **can no longer meet its objectives**.

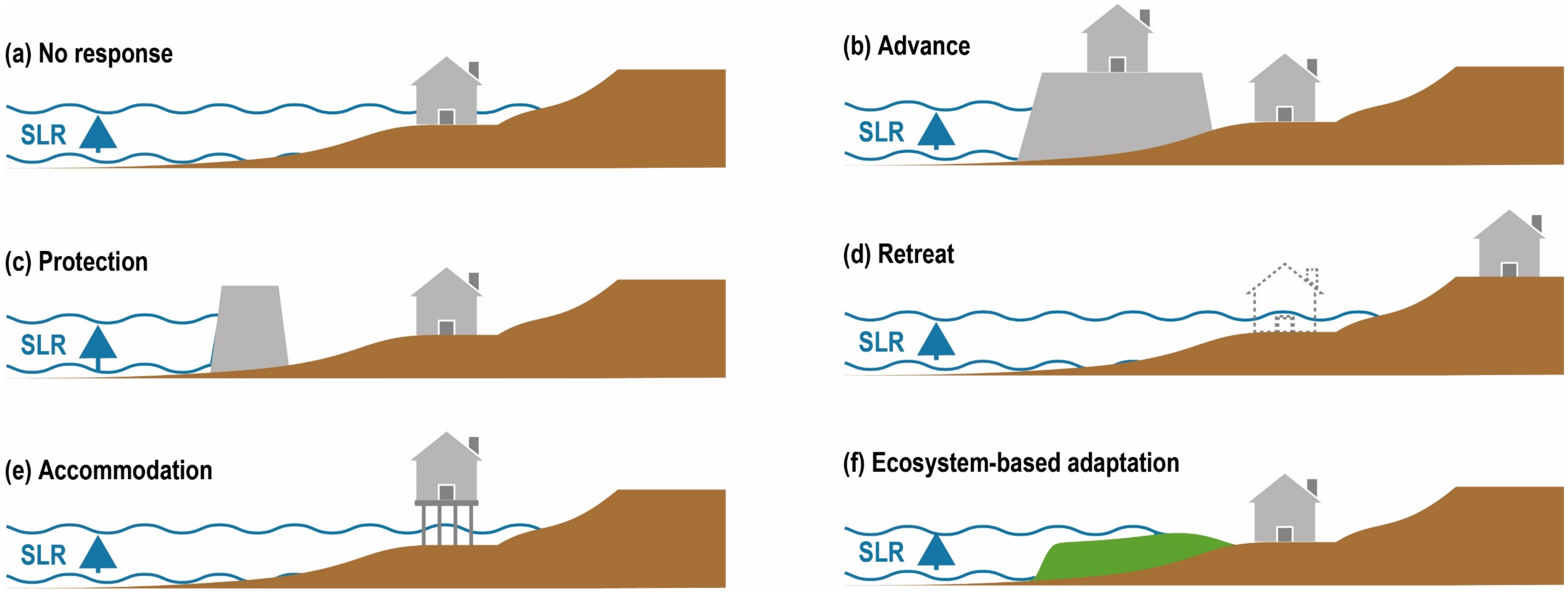
Coastal erosion



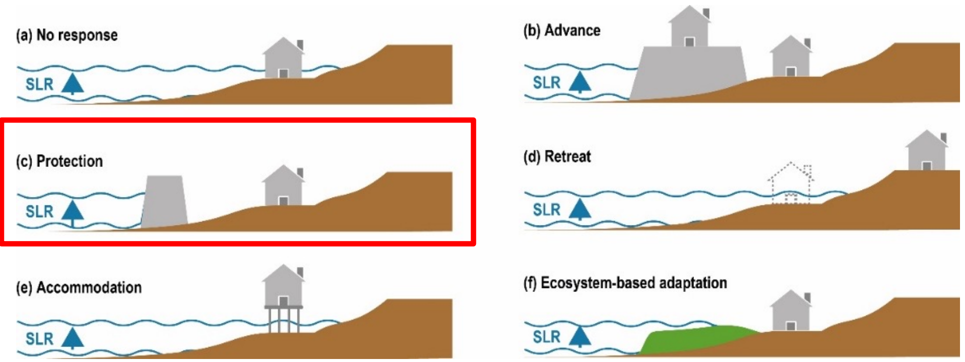
using the NASA sea level projection tool



Different types of responses to coastal risk and sea level rise



Source: IPCC



Response: Protection

(c) Responses to rising mean and extreme sea levels

The table illustrates responses and their characteristics. It is not exhaustive. Whether a response is applicable depends on geography and context.

Confidence levels (assessed for effectiveness): ●●●● = Very High ●●●= High ●● = Medium ●= Low

SROCC IPCC 2019

Responses	Potential effectiveness in terms of reducing sea level rise (SLR) risks (technical/biophysical limits)	Advantages (beyond risk reduction)	Co–benefits	Drawbacks	Economic efficiency	Governance challenges
Hard protection	Up to multiple metres of SLR {4.4.2.2.4} ●●●	Predictable levels of safety {4.4.2.2.4}	Multifunctional dikes such as for recreation, or other land use {4.4.2.2.5}	Destruction of habitat through coastal squeeze,flooding & erosion downdrift, lock–in, disastrous consequence in case of defence failure {4.3.2.4, 4.4.2.2.5}	High if the value of assets behind protection is high, as found in many urban and densely populated coastal areas {4.4.2.2.7}	Often unaffordable for poorer areas. Conflicts between objectives (e.g., conservation, safety and tourism), conflicts about the distribution of public budgets, lack of finance {4.3.3.2, 4.4.2.2.6}
Sediment–based protection	Effective but depends on sediment availability {4.4.2.2.4} ●●●	High flexibility {4.4.2.2.4}	Preservation of beaches for recreation/ tourism {4.4.2.2.5}	Destruction of habitat, where sediment is sourced {4.4.2.2.5}	High if tourism revenues are high {4.4.2.2.7}	Conflicts about the distribution of public budgets {4.4.2.2.6}

Protection strategy (sediment-based)

Zand Motor (The Netherlands)

+ 21.5 Mm³ for 20-years life time aiming to provide safety against flooding in combination with new spatial values

Aerial photographs of the Sand Engine in the period 2011–2016, looking south (Roest et al 2021).

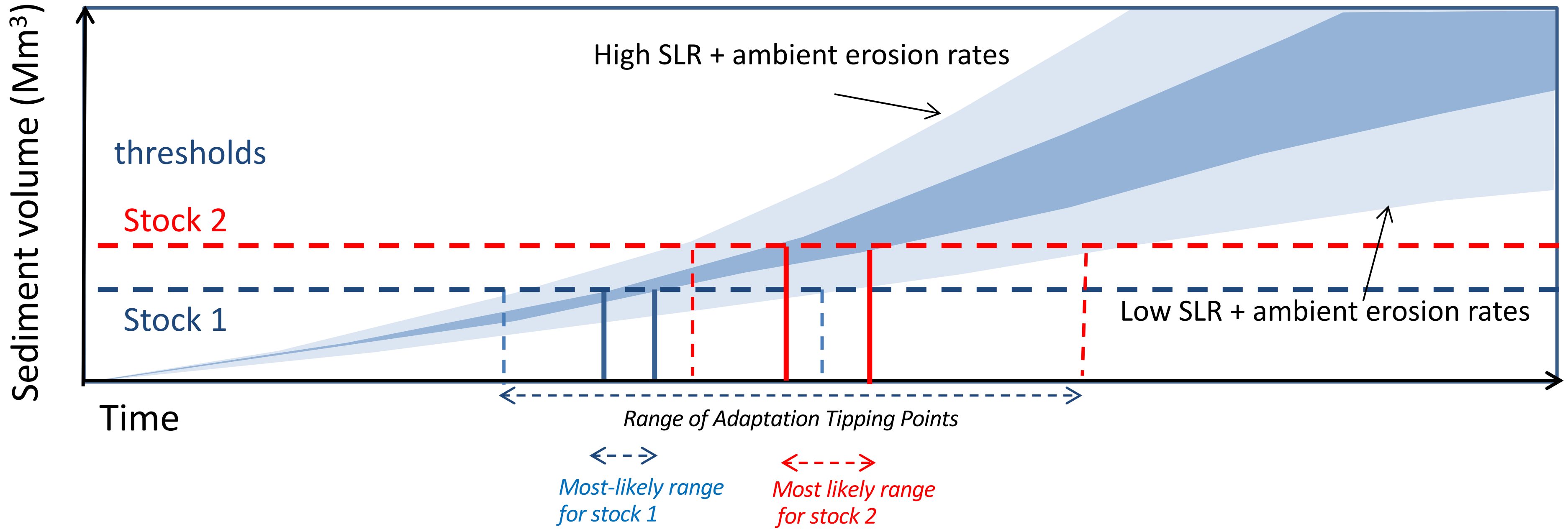
Sediment – based protection strategy

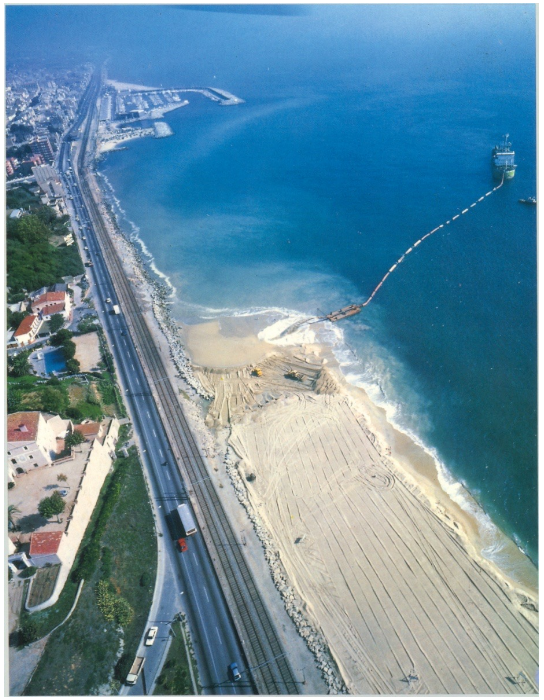
How much sand do/will we need?

Strategic sediment reservoir

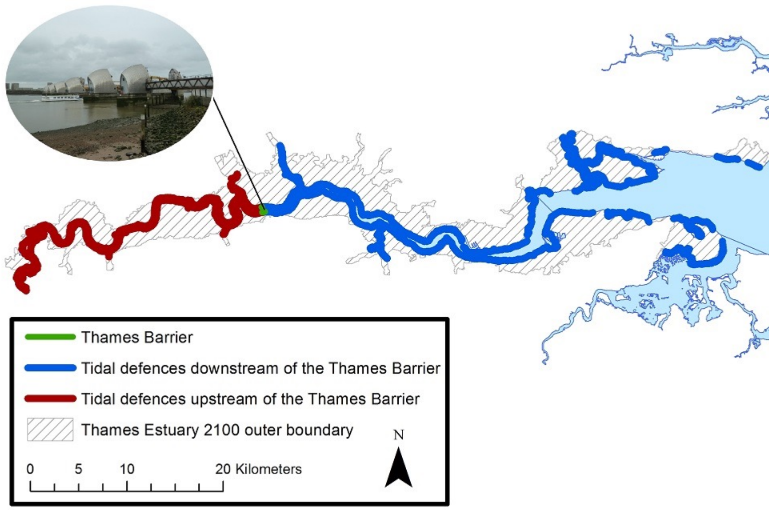
Do we have enough sand (of the required quality)?

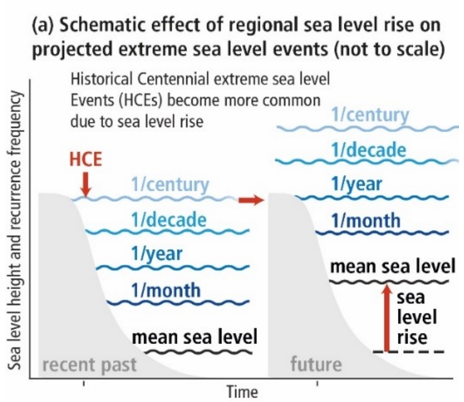
Can we afford it?



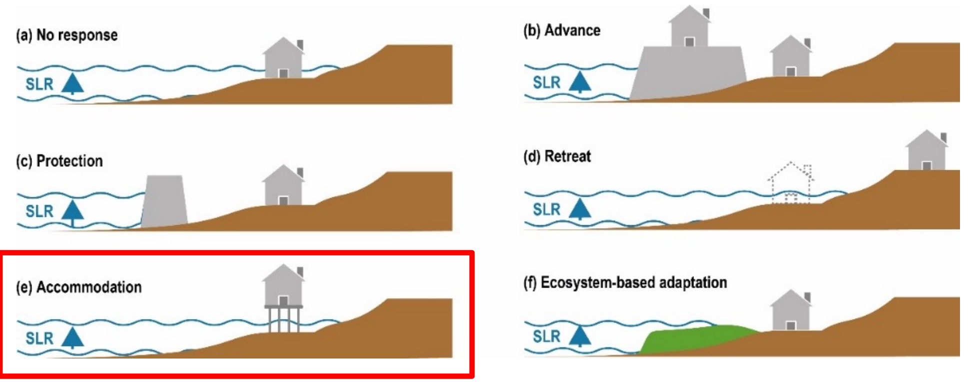


Protection strategy (hard protection)
Thames barrier (UK)





Aerial view of the Thames Barrier with closed gates
(National police air service/ gov.UK)



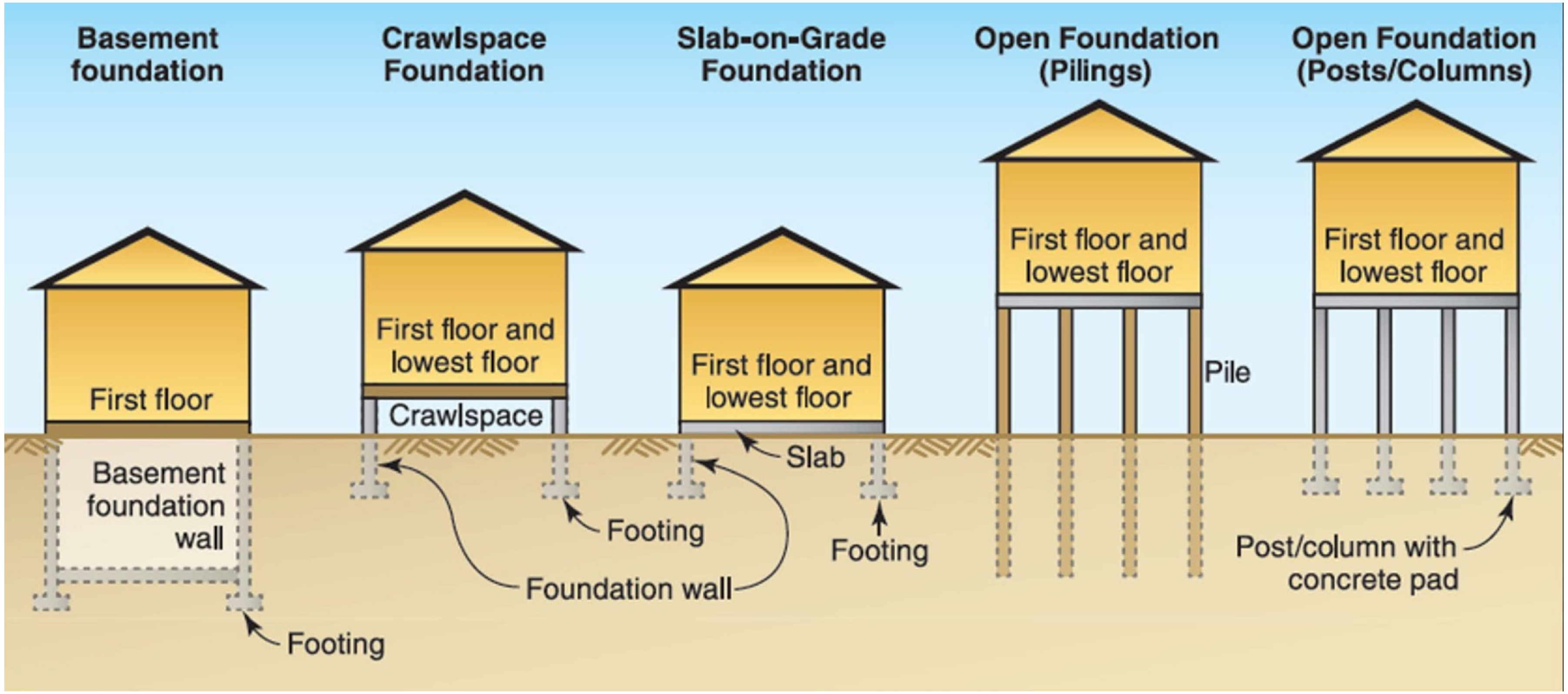
Response: **Accommodation**

Responses	Potential effectiveness in terms of reducing sea level rise (SLR) risks (technical/biophysical limits)	Advantages (beyond risk reduction)	Co–benefits	Drawbacks	Economic efficiency	Governance challenges
Coastal accommodation (Flood–proofing buildings, early warning systems for flood events, etc.)	Very effective for small SLR {4.4.2.5.4} ●●●	Mature technology; sediments deposited during floods can raise elevation {4.4.2.5.5}	Maintains landscape connectivity {4.4.2.5.5}	Does not prevent flooding/impacts {4.4.2.5.5}	Very high for early warning systems and building–scale measures {4.4.2.5.7}	Early warning systems require effective insti–tutional arrangements {4.4.2.6.6}

SROCC IPCC 2019

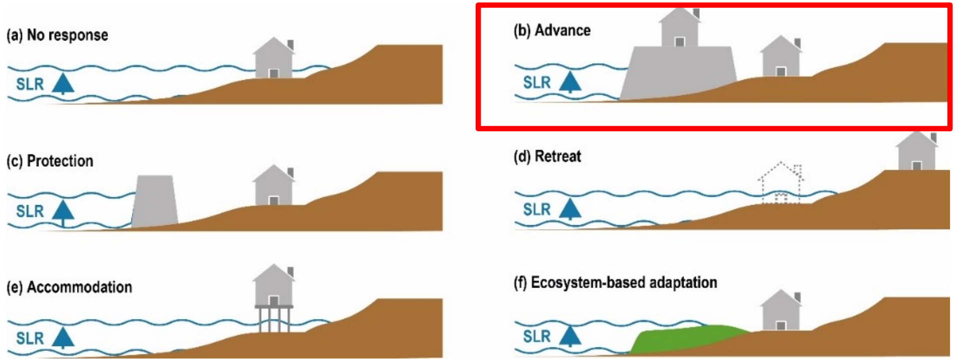
Accommodation strategy for flooding

Different home (**flood-proofing**) foundation types in coastal areas (Amini & Memari, 2021)



Rodanthe, NC, USA
Photo: H Stockdon

Makoko, Lagos (Nigeria).
Photo: Iwan Baan



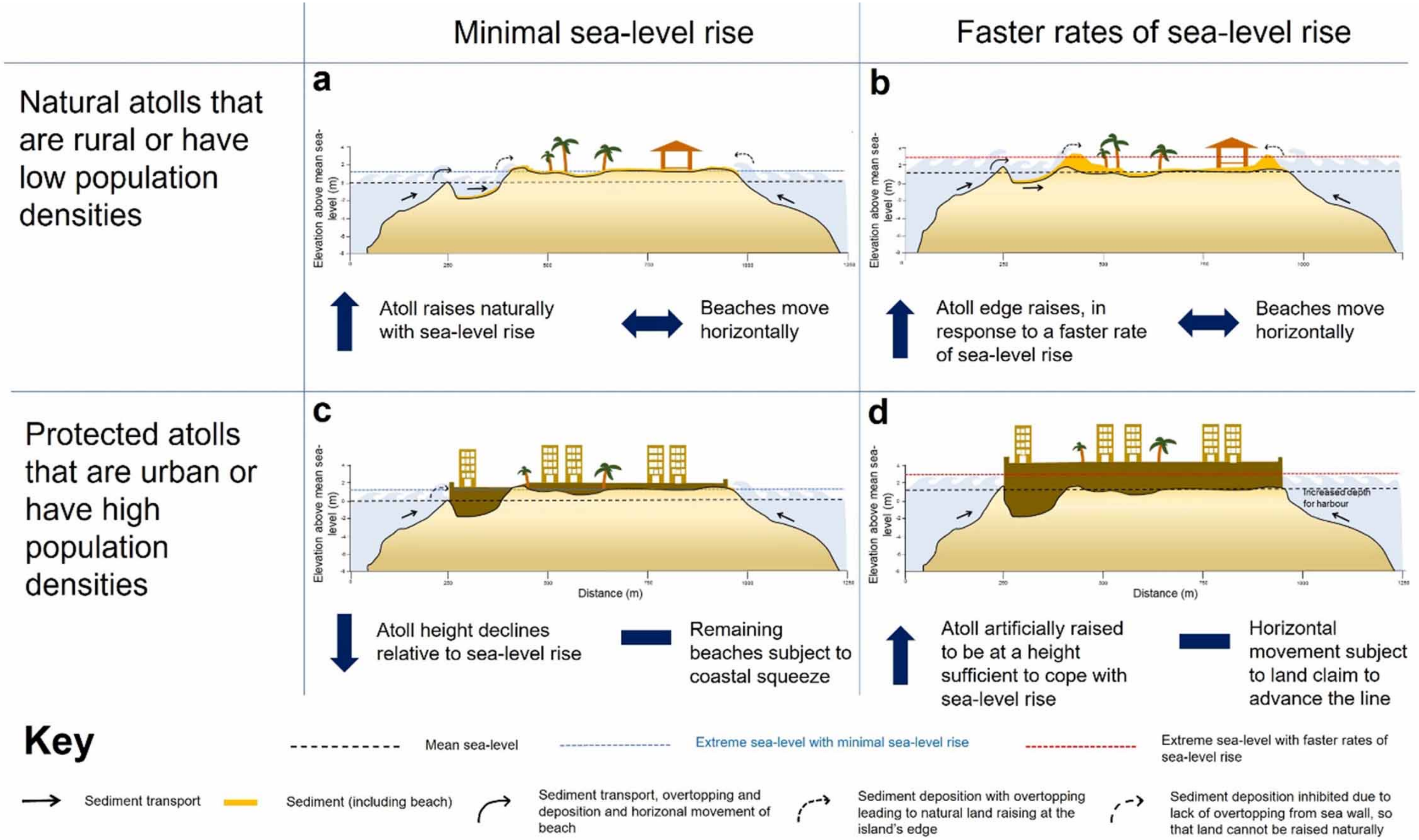
Response: Advance

Responses	Potential effectiveness in terms of reducing sea level rise (SLR) risks (technical/biophysical limits)	Advantages (beyond risk reduction)	Co–benefits	Drawbacks	Economic efficiency	Governance challenges
Coastal advance	Up to multiple metres of SLR {4.4.2.2.4} ●●●	Predictable levels of safety {4.4.2.2.4}	Generates land and land sale revenues that can be used to finance adaptation {4.4.2.4.5}	Groundwater salinisa–tion, enhanced erosion and loss of coastal ecosystems and habitat {4.4.2.4.5}	Very high if land prices are high as found in many urban coasts {4.4.2.4.7}	Often unaffordable for poorer areas. Social conflicts with regards to access and distribution of new land {4.4.2.4.6}

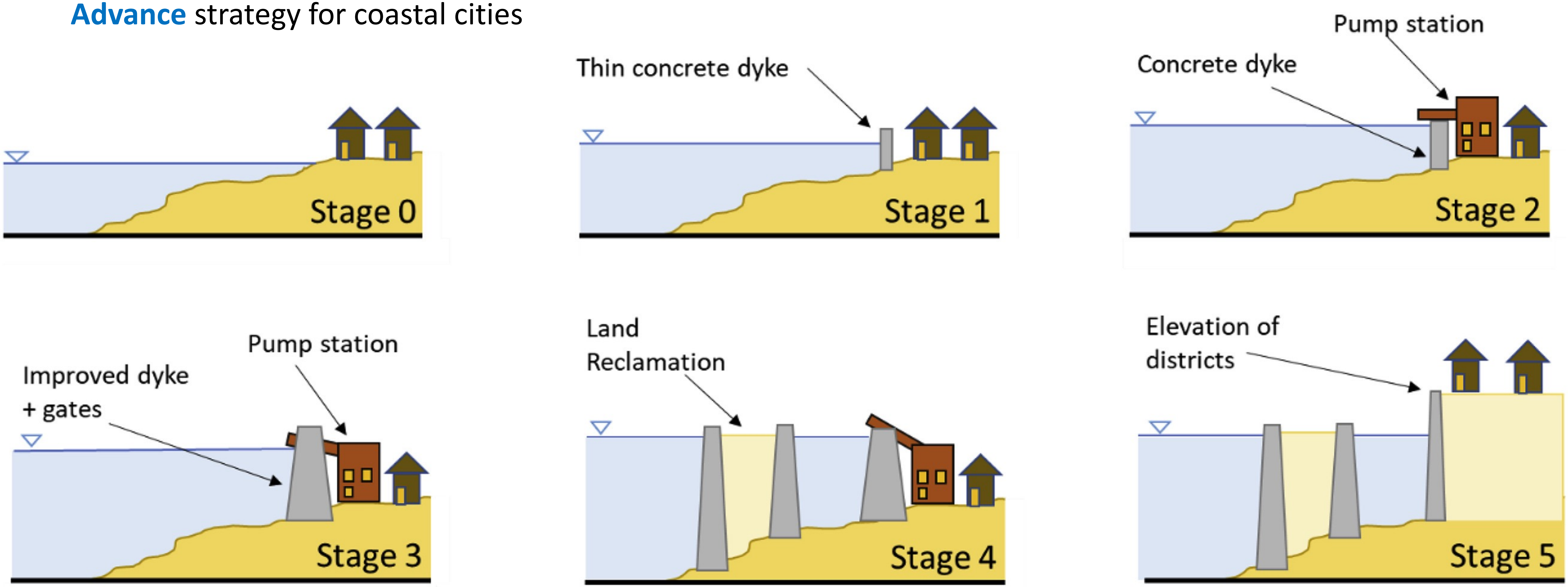
SROCC IPCC 2019

Advance strategy for atoll islands (e.g. Maldives)

(Brown et al. 2023)

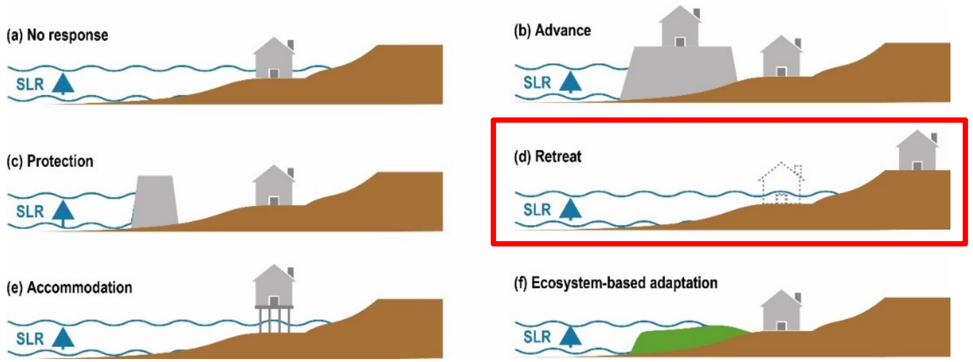


Advance strategy for coastal cities



Schematic representation of the stages of the adaptation process to SLR (by advance-land reclamation) in coastal cities (Tokyo, JP)

(Esteban et al 2020)

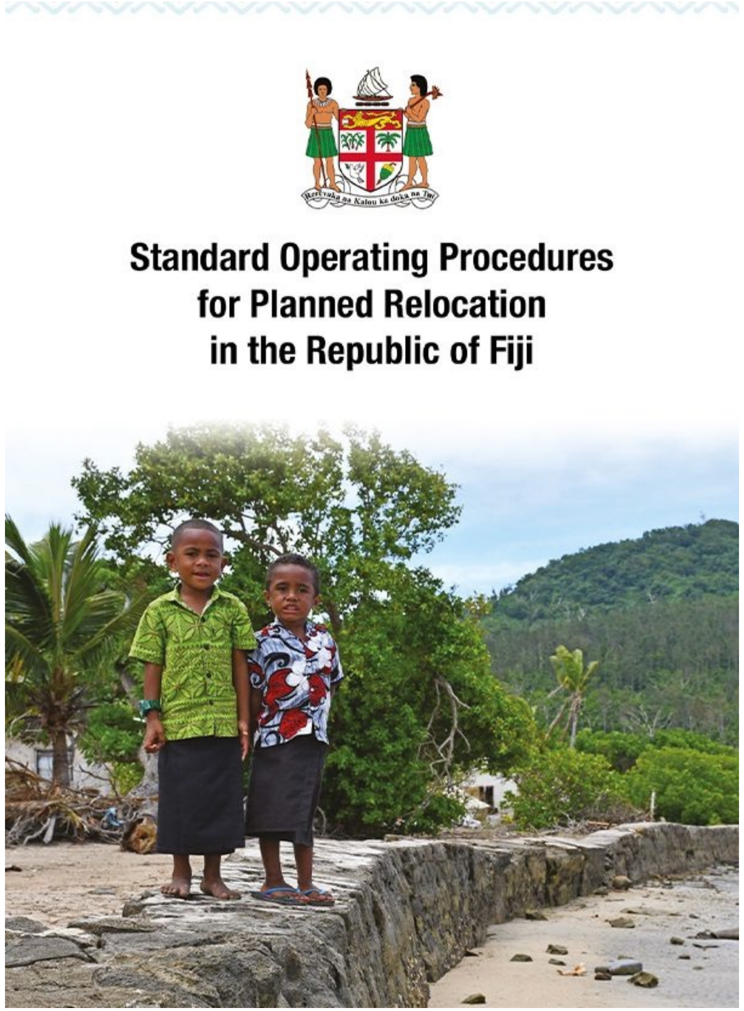


Response: **Retreat**

SROCC IPCC 2019

Responses		Potential effectiveness in terms of reducing sea level rise (SLR) risks (technical/biophysical limits)	Advantages (beyond risk reduction)	Co–benefits	Drawbacks	Economic efficiency	Governance challenges
Retreat	**Planned relocation**	Effective if alternative safe localities are available {4.4.2.6.4} ●●●	Sea level risks at origin can be eliminated {4.4.2.6.4}	Access to improved services (health, education, housing), job opportunities and economic growth {4.4.2.6.5}	Loss of social cohesion, cultural identity and well–being. Depressed services (health, education, housing), job opportunities and economic growth {4.4.2.6.5}	Limited evidence [4.4.2.6.7}	Reconciling the divergent interests arising from relocating people from point of origin and destination {4.4.2.6.6}
	Forced displacement	Addresses only immediate risk at place of origin	Not applicable	Not applicable	Range from loss of life to loss of livelihoods and sovereignty {4.4.2.6.5}	Not applicable	Raises complex humanitarian questions on livelihoods, human rights and equity {4.4.2.6.6}

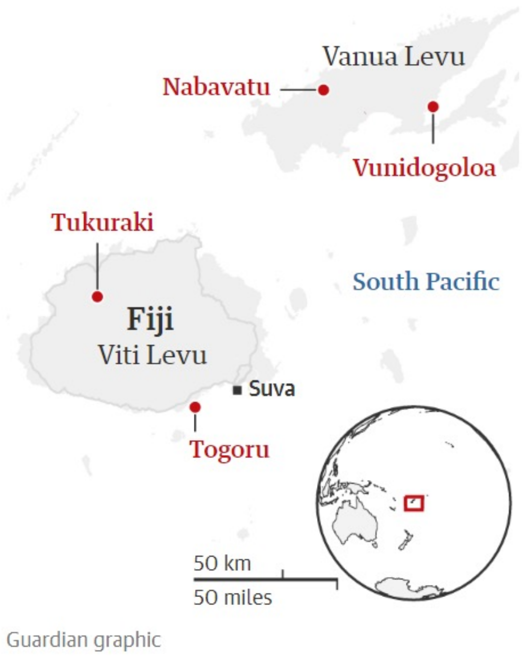
Retreat strategy
Planned relocation in Fiji islands



At present, **42 Fijian villages have been earmarked for potential relocation in the next five to 10 years**, owing to the impacts of climate crisis. Six have already been moved. Every new cyclone or disaster brings with it the risk of yet more villages being added to the list.

Discussions about moving Vunidogoloa started in earnest around 2004. …. It took the **better part of a decade before** the new site, about a mile farther inland and higher up, was ready for them.

(The Guardian)

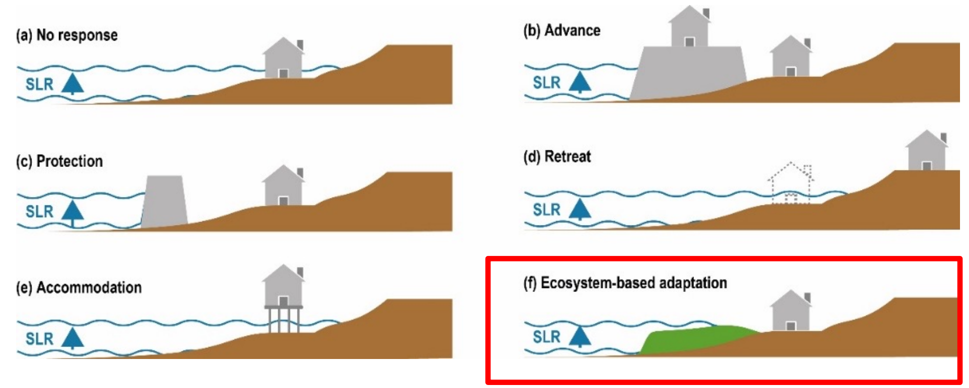


Retreat strategy

Managed realignment

Medmerry (UK Environment Agency)

Spatial planning – new setbacks (Tordera delta, Barcelona, Spain)



Response: **Ecosystem-based**

SROCC IPCC 2019

Responses		Potential effectiveness in terms of reducing	Advantages (beyond risk reduction)	Co–benefits	Drawbacks	Economic efficiency	Governance challenges
Ecosystem based adaptation	**Coral conservation**	Effective up to 0.5 cm yr^{-1} SLR. ●● Strongly limited by ocean warming and acidification. Constrained at 1.5°C warming and lost at 2°C at many places. {4.3.3.5.2, 4.4.2.3.2, 5.3.4} ●●●	Opportunity for community involvement, {4.4.2.3.1}	Habitat gain, biodiversity, carbon sequestration, income from tourism, enhanced fishery productivity, improved water quality. Provision of food, medicine, fuel, wood and cultural benefits {4.4.2.3.5}	Long–term effectiveness depends on ocean warming, acidification and emission scenarios {4.3.3.5.2., 4.4.2.3.2}	Limited evidence on benefit–cost ratios; Depends on population density and the availability of land {4.4.2.3.7}	Permits for implementation are difficult to obtain. Lack of finance. Lack of enforcement of conservation policies. EbA options dismissed due to short–term economic interest, availability of land {4.4.2.3.6}
	Coral restoration						
	Wetland conservation (Marshes, Mangroves)	Effective up to 0.5–1 cm yr^{-1} SLR, ●● decreased at 2°C {4.3.3.5.1, 4.4.2.3.2, 5.3.7} ●●●			Safety levels less predictable, development benefits not realized {4.4.2.3.5, 4.4.2.3.2}		
	Wetland restoration (Marshes, Mangroves)				Safety levels less predictable, a lot of land required, barriers for landward expan–sion of ecosystems has to be removed {4.4.2.3.5, 4.4.2.3.2}		

Ecosystem-based strategy
Ecosystem restoration

Mangrove restoration (Nigeria)

Coastal dunes restoration (Spain)

Ecosystem-based strategy

Managed realignment +

coastal landscape restoration

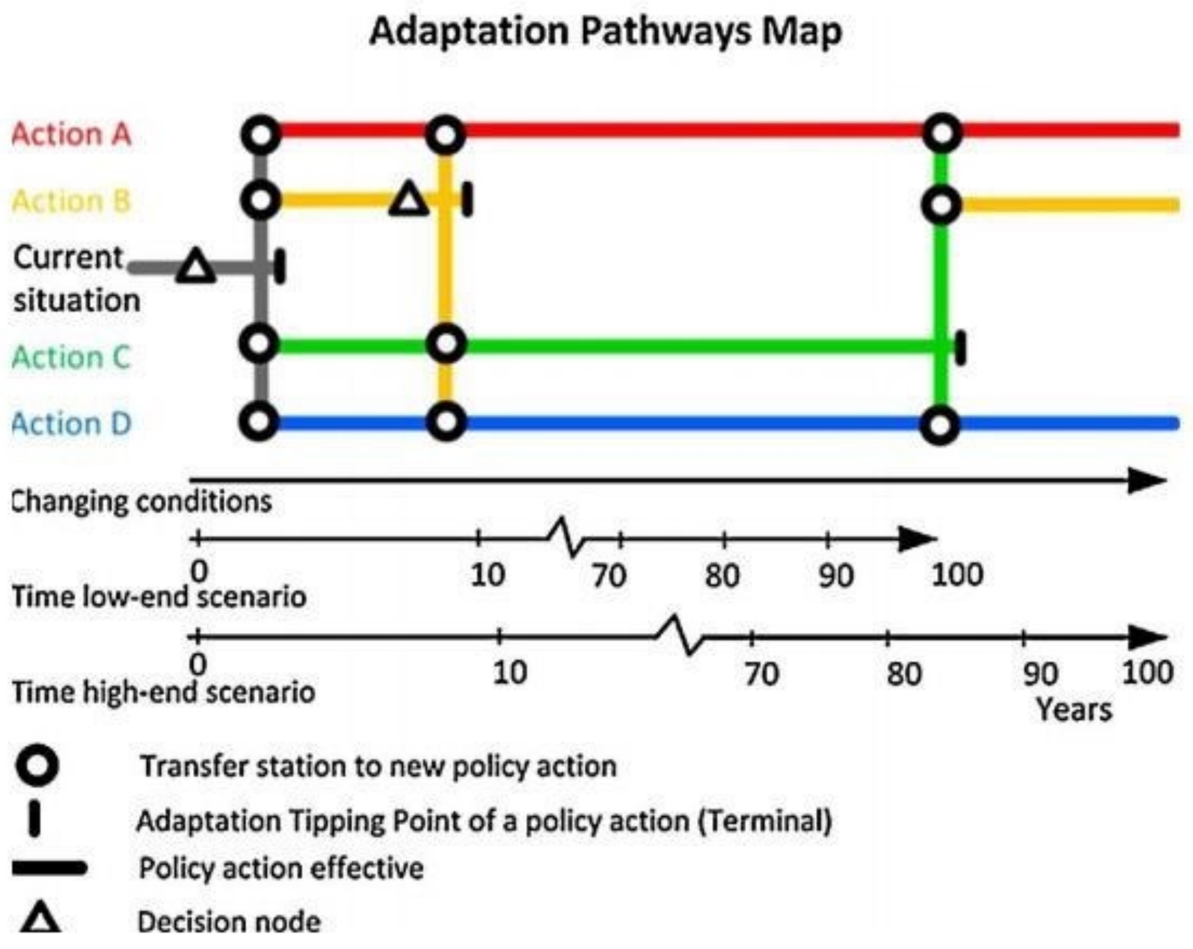
(dunes + wetlands) in the Ebro delta (Spain)

The adaptation pathways approach

Adaptation pathways are **sequences of linked** (portfolios of) **actions** that can be implemented as conditions change.

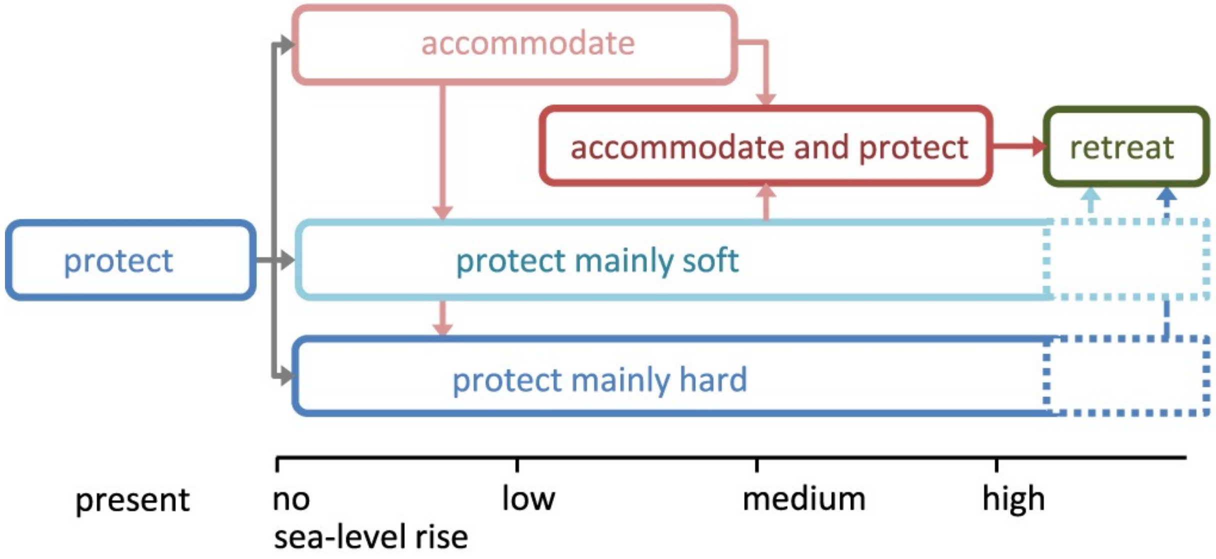
The adaptation pathways approach helps to make decisions about adaptation in the face of the **high uncertainty** associated with the impacts of SLR.

(Haasnoot et al. 2019)

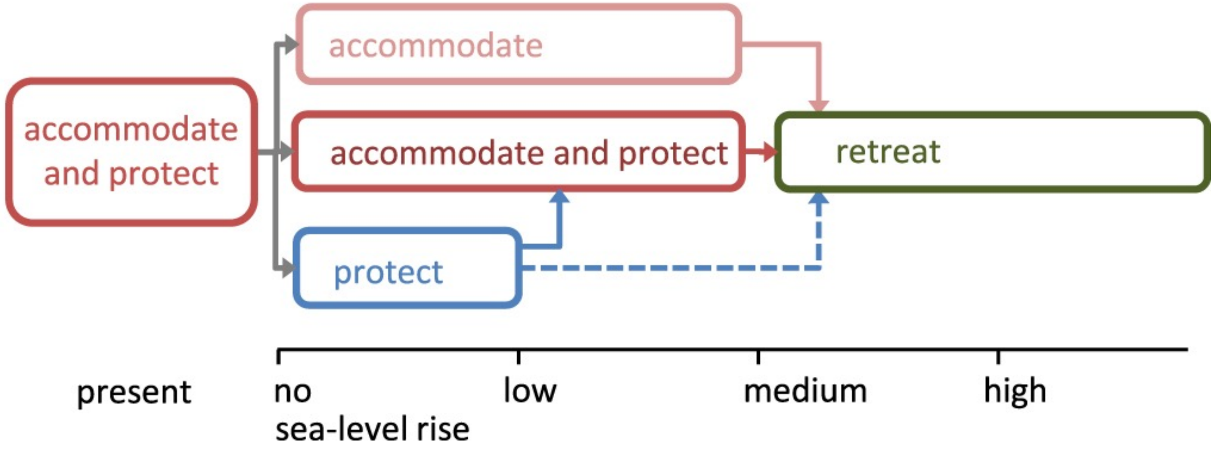


Zandvoort et al. (2017)

Urban archetypes



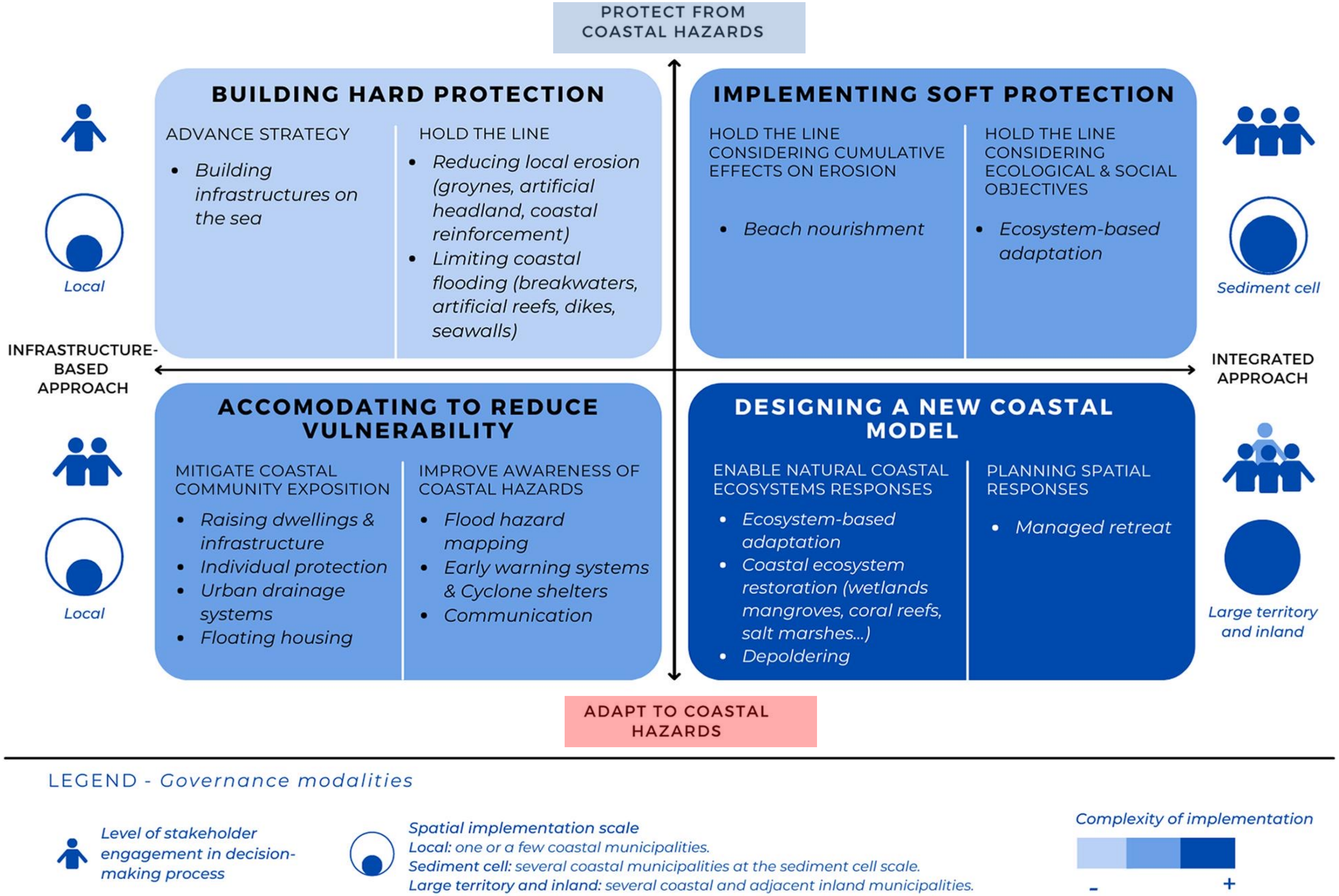
Rural archetypes



In **urban environments**, the immediate priority is to **protect**. The path of protection tends to be **self-reinforcing** -> *people and assets tend to accumulate in protected areas, in turn requiring higher protection*.

In **rural land** hard protection is difficult to motivate. Present interventions are minimal and mostly in the direction of **accommodate**, with a possibility to delay the TP by combining with protection measures (of relatively small investment). With *medium to high sea-levels* **retreat** remains the last option, unless new technologies delay the TP and extend the lifetime of accommodate measures.

(Haasnoot et al. 2019)



Governance archetypes of adaptation strategies to sea level rise according to the **complexity of their implementation**, both institutionally and technically.

(Bongarts Lebbe et al. 2021)

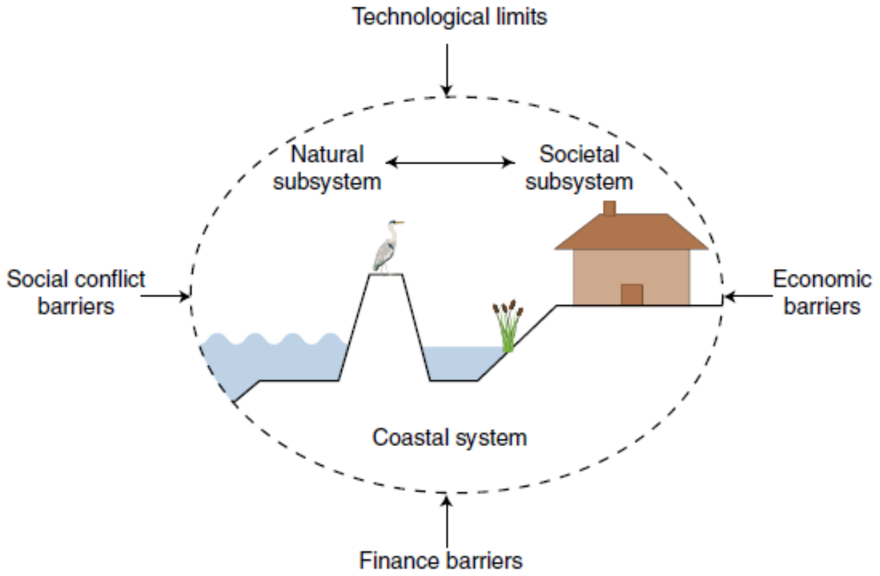
Constraints to coastal adaptation

Technological limits -> there are no adaptation options available to effectively reduce the impacts of SLR (considering the time needed for implementing options and maintaining the coastal functionality).

Barriers

Economic -> if the implementation and maintenance of adaptation are more costly in monetary terms than the impacts they avoid
Financing -> if it is difficult to access financial resources for adaptation.
Social conflict -> whenever stakeholders' conflicting interests impede or exacerbate adaptation.

Limits beyond which human activities cannot be maintained



Barriers which can be overcome through adequate efforts

Hinkel et al. (2018)

Take home messages

- Sea-level will continue to rise -> coastal impacts will increase -> **coastal adaptation** will be needed.
- Coastal impacts **can be avoided by preventing new developments** in exposed coastal locations.
- Responses to sea-level rise are **more effective** if combined, sequenced, planned well ahead; aligned with sociocultural values and development priorities; underpinned by inclusive community engagement process.
- Adaptation to manage risks from projected sea level rise **typically require decades** to implement and institutionalise.

References

- Amini, M, Memari, AM (2021). Comparative review and assessment of various flood retrofit methods for low-rise residential buildings in coastal areas. *Natural Hazards Review*, 22(3), 04021009.
- Bongarts Lebbe, T, Rey-Valette, H, Chaumillon, É, Camus, G, et al. (2021). Designing coastal adaptation strategies to tackle sea level rise. *Frontiers in Marine Science*, 1640.
- Brown, S, Nicholls, RJ, Bloodworth, A, Bragg, O, et al. (2023). Pathways to sustain atolls under rising sea levels through land claim and island raising. *Environmental Research: Climate*, 2(1), 015005.
- Esteban, M, Takagi, H, Jamero, L, Chadwick, C, et al. (2020). Adaptation to sea level rise: Learning from present examples of land subsidence. *Ocean & Coastal Management*, 189, 104852.
- Haasnoot, M, Brown S, Scussolini, P, Jiménez JA, Vafeidis A, Nicholls RJ. 2019. Generic adaptation pathways for coastal archetypes under uncertain sea-level rise. *Environmental Research Communications*, 1, 7, 071006.
- Hinkel J, Aerts J, Brown S, Jiménez JA, et al. 2018 The ability of societies to adapt to 21st century sea-level rise. *Nat Clim Change*, 8, 570–578,
- Kwadijk, JC, Haasnoot, M, Mulder, JP, Hoogvliet, MM et al. (2010). Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. *Wiley interdisciplinary reviews: climate change*, 1(5), 729-740.
- López-Doriga, U, Jiménez JA, Bisaro, A, Hinkel, J. 2020. Financing and implementation of adaptation measures to climate change along the Spanish coast. *Science of the Total Environment*, 712, 135685.
- Losada, IJ, Toimil, A, Munoz, A, Garcia-Fletcher, AP, Diaz-Simal, P. (2019). A planning strategy for the adaptation of coastal areas to climate change: The Spanish case. *Ocean & Coastal Management*, 182, 104983.
- Pörtner, HO et al. (2019). *The ocean and cryosphere in a changing climate. IPCC special report on the ocean and cryosphere in a changing climate (SROCC)*, 1155.
- Roest, B, De Vries, S, De Schipper, M, Aarninkhof, S (2021). Observed changes of a mega feeder nourishment in a coastal cell: Five years of sand engine morphodynamics. *Journal of Marine Science and Engineering*, 9(1), 37.
- Zandvoort et al. (2017). Adaptation pathways in planning for uncertain climate change: Applications in Portugal, the Czech Republic and the Netherlands. *Environmental Science and Policy* 78 (2017) 18–26.

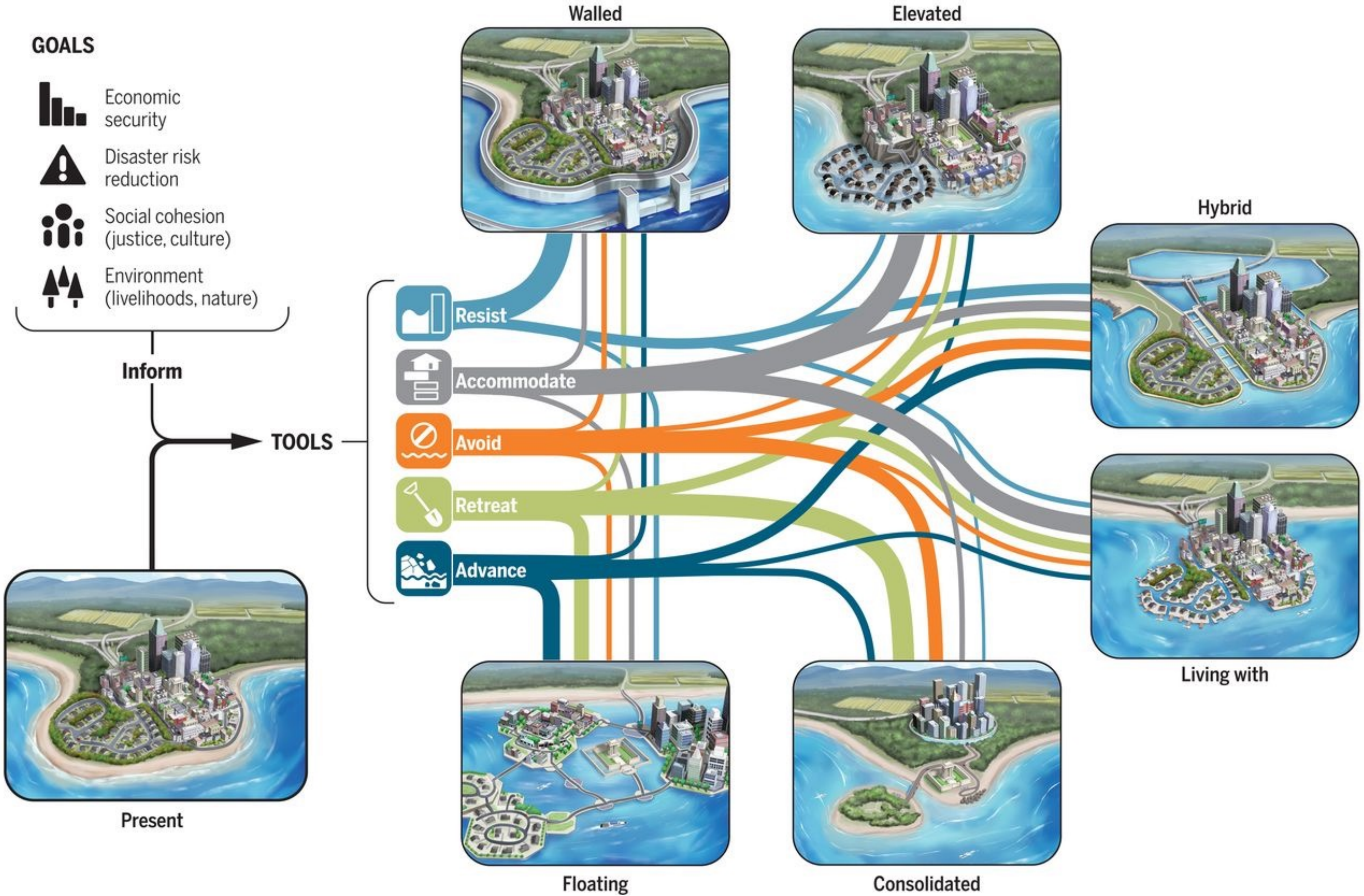
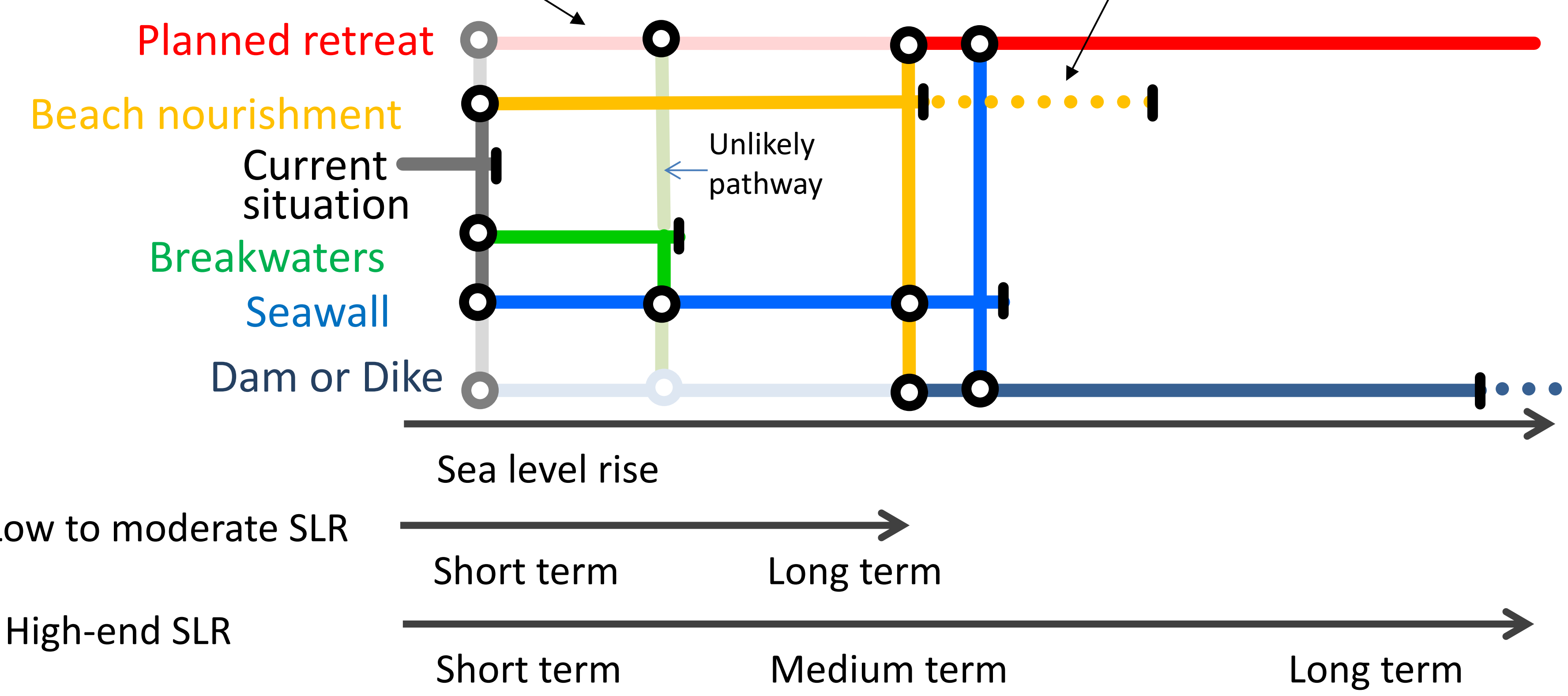


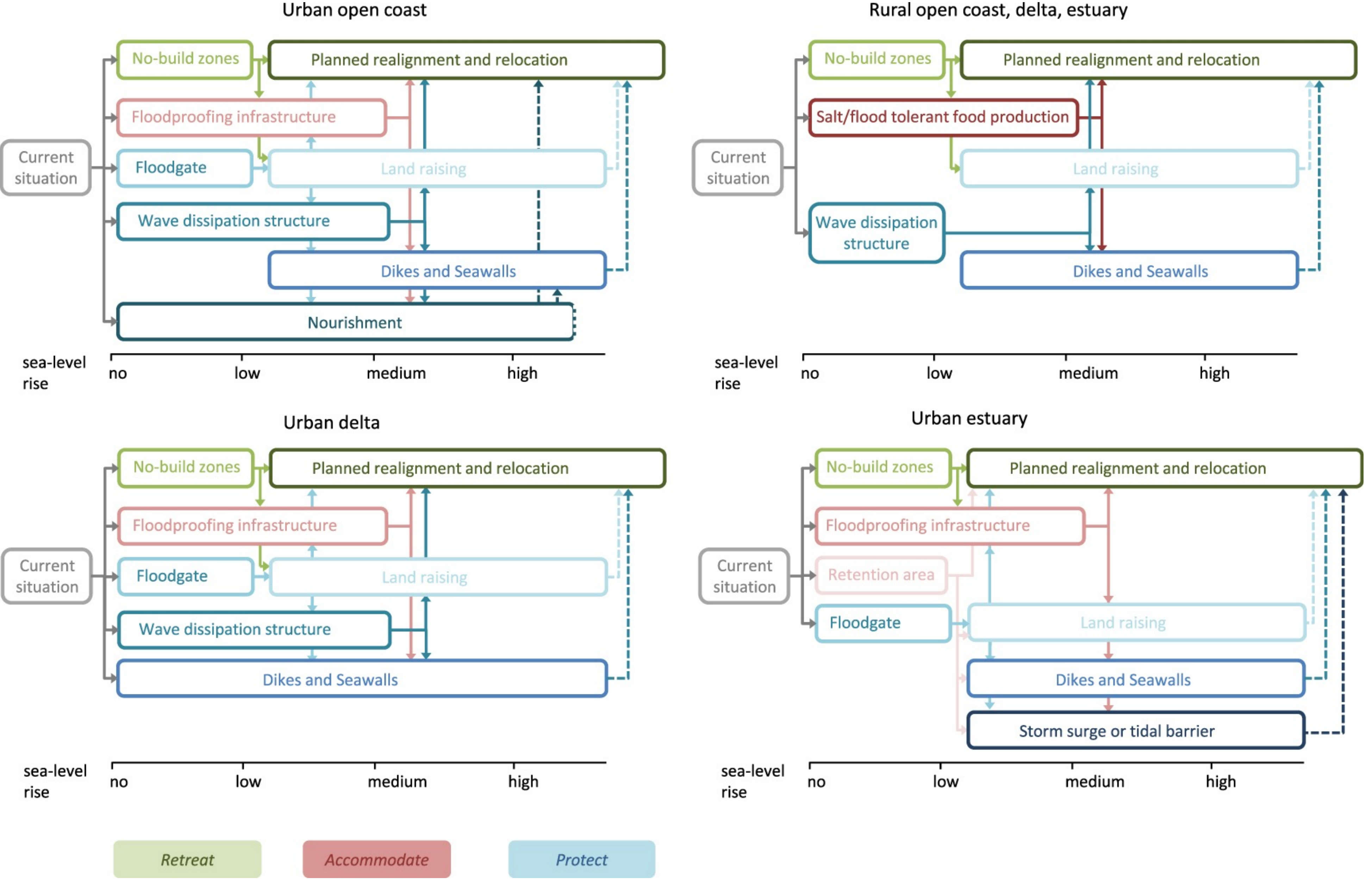
Fig. 1 Holistic pathways of climate transformation.
(Bottom left) A hypothetical present-day settlement (dense city, suburban and periurban communities, and rural areas). (Right) Six possible futures. Adaptive pathways between the present day and the future will be shaped by climate risks, limits to adaptation, and societal goals. Strategic, managed retreat (green) will have some role in each future, along with other categories of response. The degree of retreat varies across scenarios (e.g., removal of a few structures to create space for retention ponds and pumping in the hybrid scenario or large-scale relocations in the consolidated or floating scenario). A decision not to engage in strategic, managed retreat complicates the pursuit of these futures and may eliminate certain futures as options. (Mach & Siders 2021)

Generic adaptation pathway (urban coast)

Action not usually taken in the short term due to risk of overinvestment, time required for actions, lack of social support, etc.

Uncertainty in ATP
Enough sediment availability?

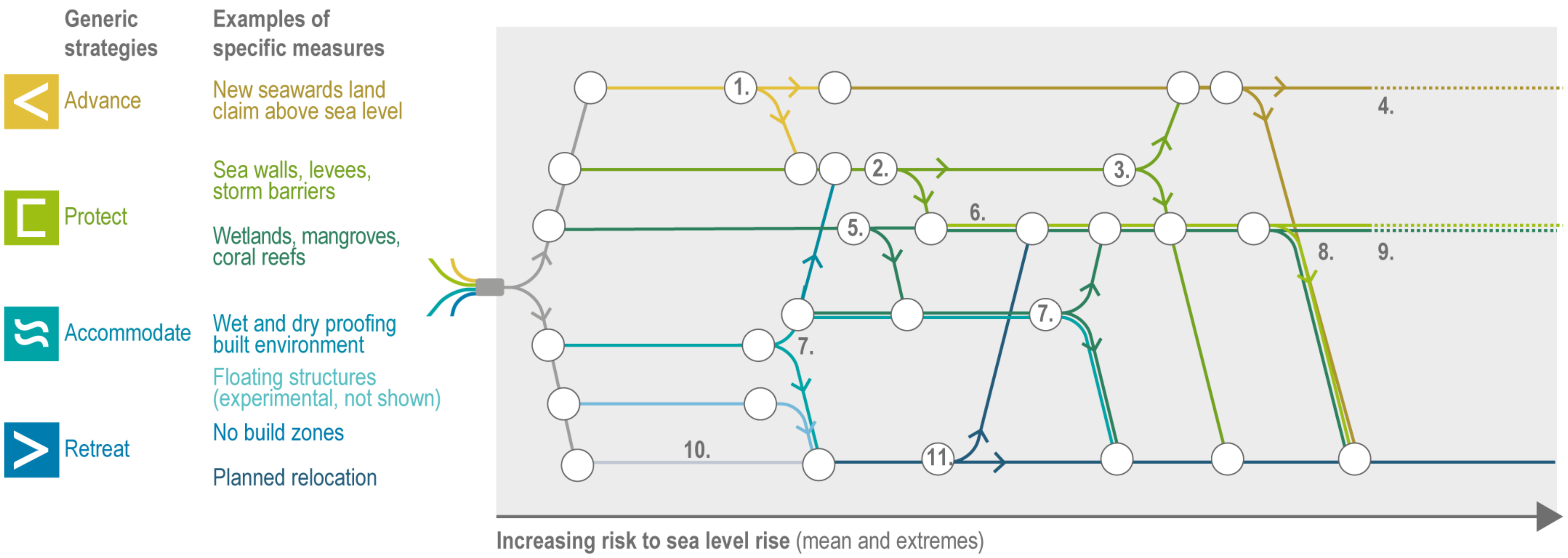




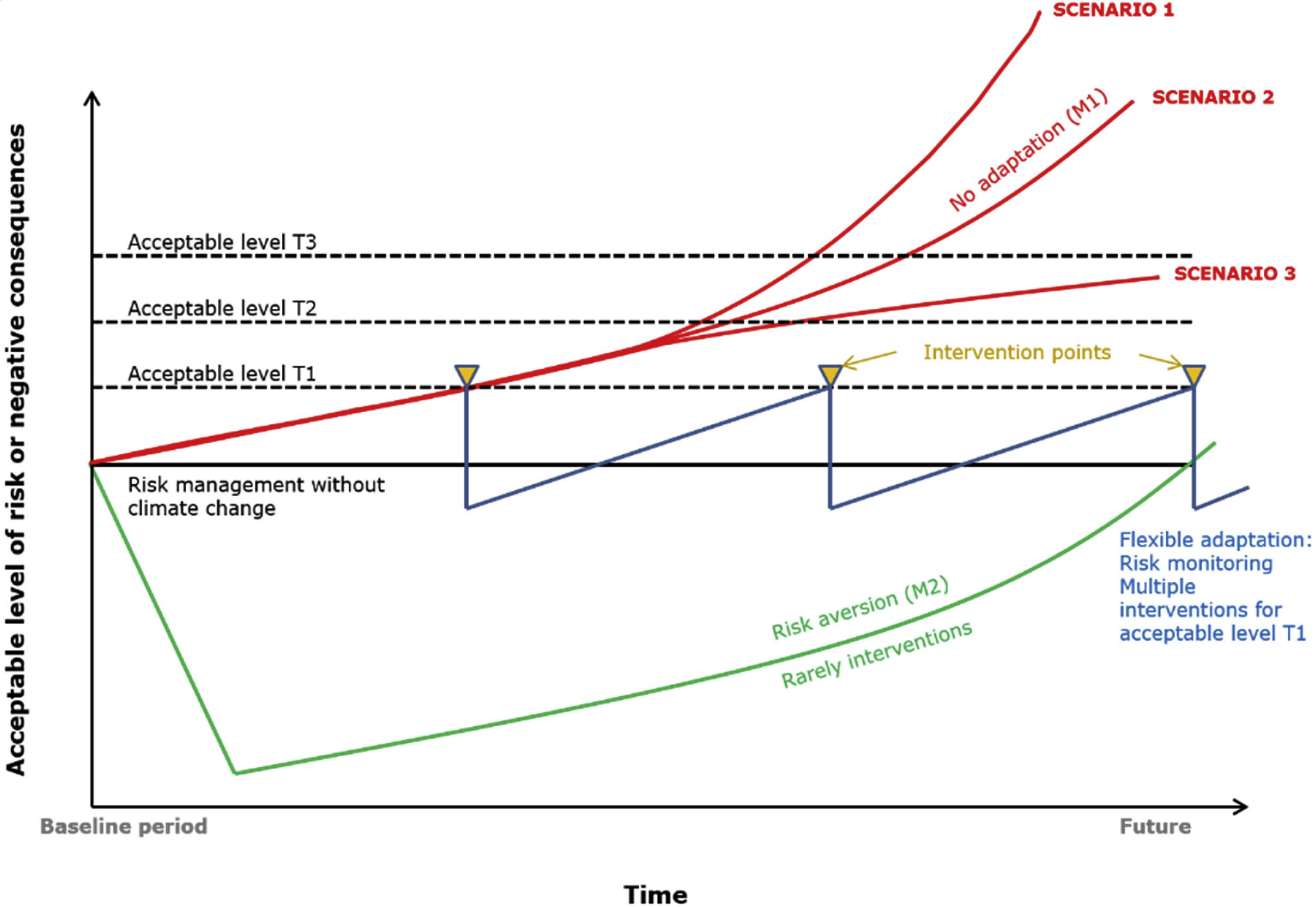
Adaptation pathways for the coastal archetypes existing of sequences of (portfolio) of adaptation actions (coloured boxes). The length of the boxes represents the interval of sea-level rise for which the adaptation measure is effective, i.e. before it reaches its adaptation or opportunity tipping points. Combining measures could extend the design life of a measure (Haasnoot et al 2019).

Solution space for coastal cities and settlements by the sea

(a) Generic adaptation pathways for coastal cities and settlements to sea level rise



1. Successful pilot, lack of development space triggers advance, or protect due to lack of support, time or finance.
2. Preference for nature-based solutions.
3. Unaffordable, salinisation, pumping limit, lack of support.
4. Unaffordable, pumping limit, lack of time, support, knowledge, material.
5. Warming, limited space, human pressures, frequent flooding require additional measures.
6. Hybrid strategy.
7. Frequent flooding, flooding creates access problems.
8. Warming, limited space, human pressures, frequent flooding.
9. Unaffordable, salinisation, pumping limit, lack of support.
10. Long lead time to align with social goals and ensure just outcomes.
11. Lack of acceptance and equity triggers shift.



Risk management alternatives (Losada et al 2019).