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Global Investment Costs for Coastal Defence Through the 21st Century

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Plan

- Background
- Methodology
  - The DIVA model
  - Approach and cost estimates
- Illustrative results
  - Length of defences
  - Capital and maintenance costs
- Concluding thoughts

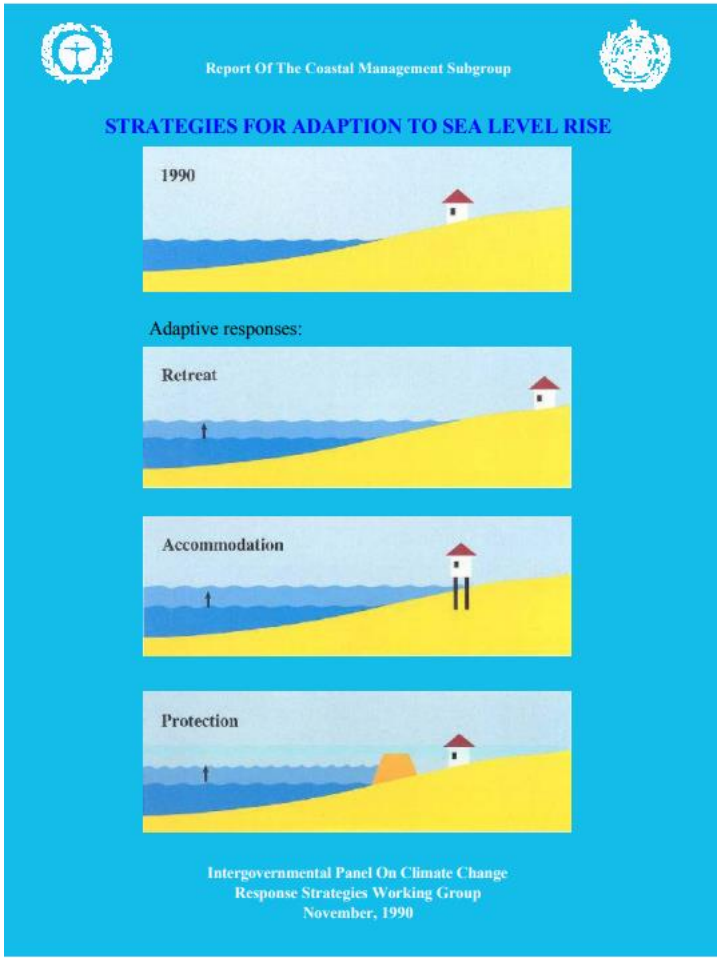
Background

- KEY QUESTION: What are plausible cost estimates for coastal defence infrastructure against coastal flooding through the 21st Century?
- Under changing population, economy and climate-induced sea-level rise (as well as subsidence).
- Asks what would the protection costs be if we followed a pre-defined stylized protection strategy at a global scale.
- Hence NOT economic optimization approaches
- Both capital investment and maintenance costs are considered.

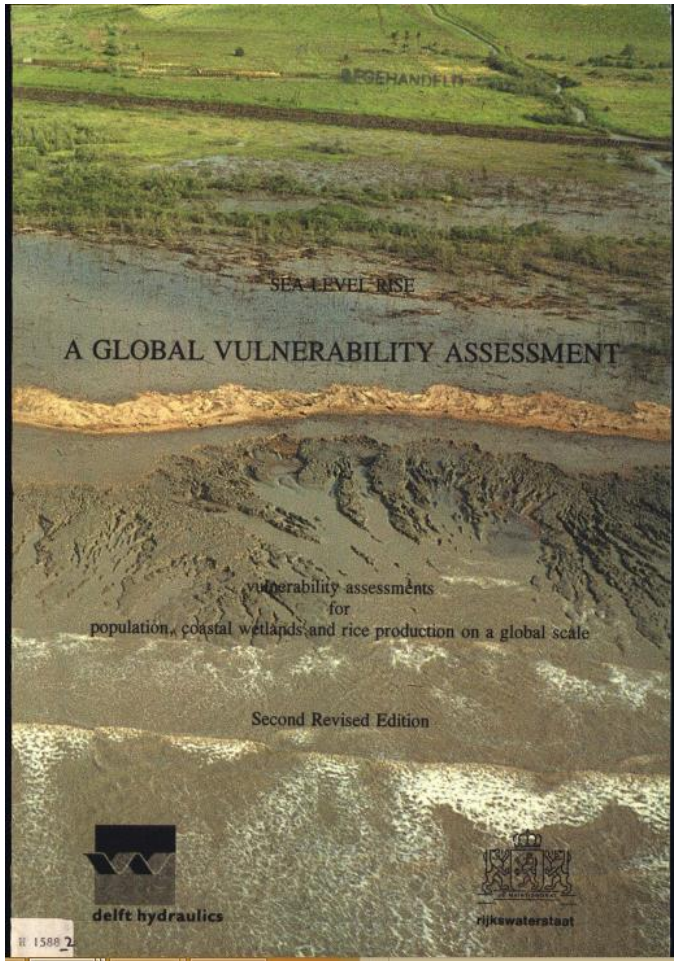
Coastal Flood Defences in NW Europe

Global protection costs for sea-level rise

A long history



(a) 1990



(b) 1993

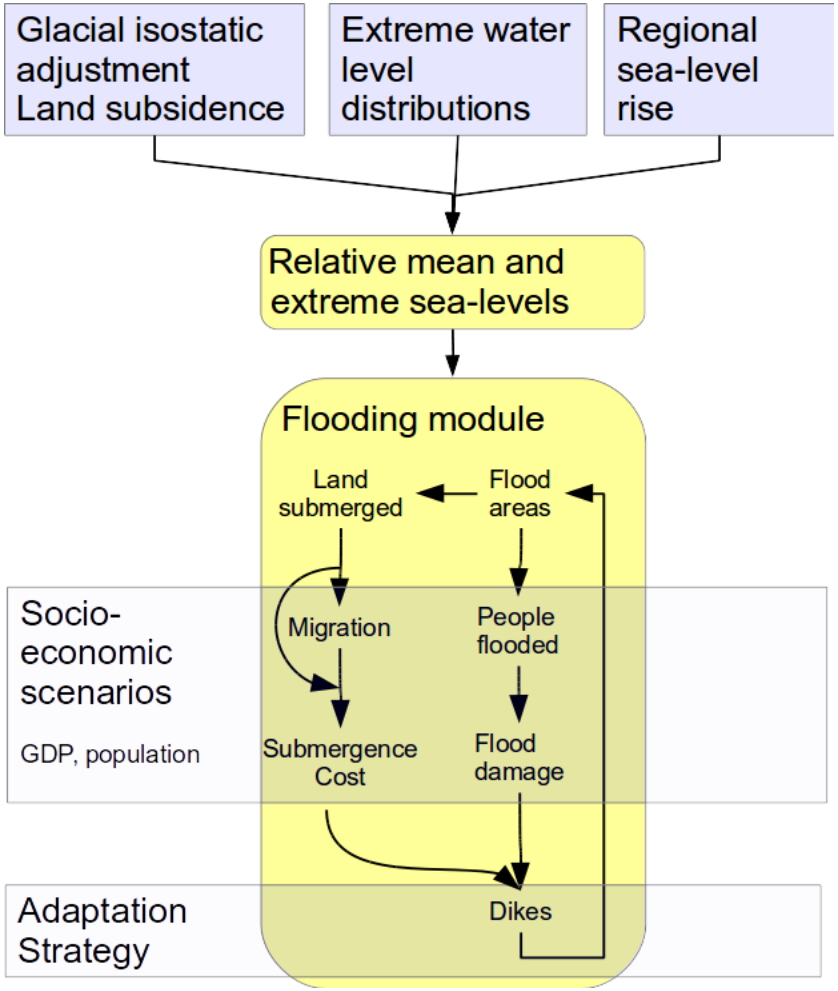
Global protection costs for sea-level rise

Study	Cost Estimate (2014 USD)	Comments
Dronkers et al., 1990	$815 billion	1-m rise, capital costs mainly reflecting flood protection and other aspects (e.g. port upgrade).
Hoozemans et al., 1993	$1,630 billion	1-m rise, as Dronkers et al. (1990) with better consideration of storm surge hazard and protection needs.
Tol, 2002	$1,524 billion	1-m rise. Optimum (benefit-cost) analysis using the FUND model. Capital costs only.
Hinkel et al. 2014	$3,000 to $6,100 billion	0.6-m to 1.23-m rise (RCP8.5 emissions). Demand for safety approach (protection scenario rather than benefit-cost approach). Costs include capital and maintenance costs of dikes built since 2005.

Methods

DIVA Flood Module (after Hinkel et al., 2014)

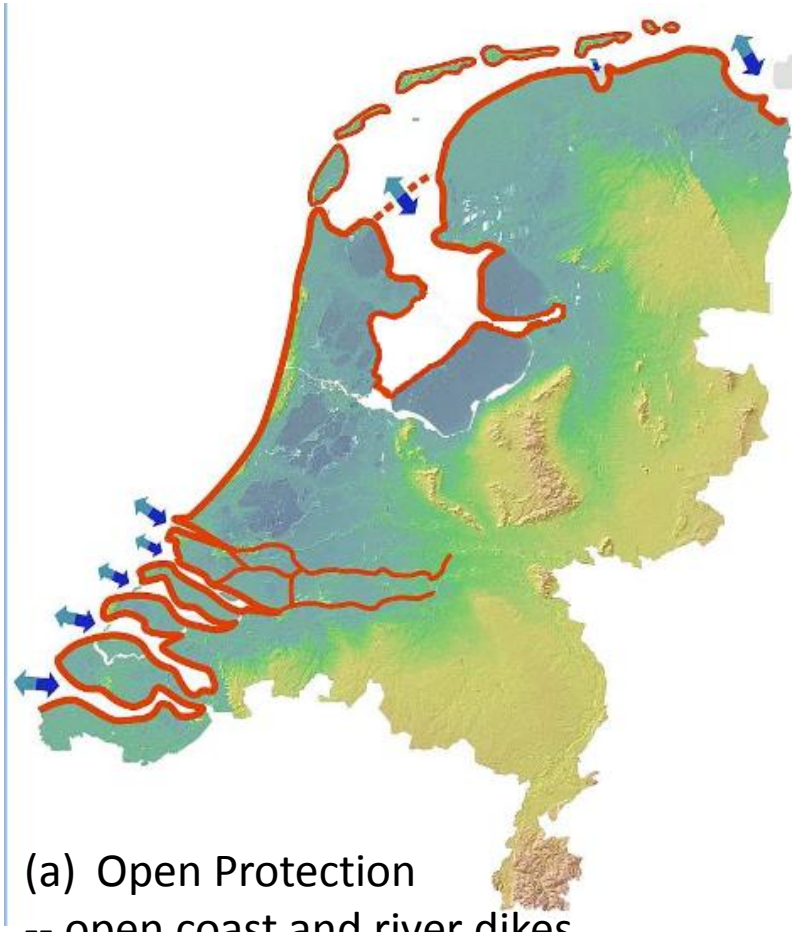
DIVA (Dynamic Interactive Vulnerability Assessment) of coastal floods, erosion and wetland change. A set of algorithms and a global database based on about 12,000 linear segments



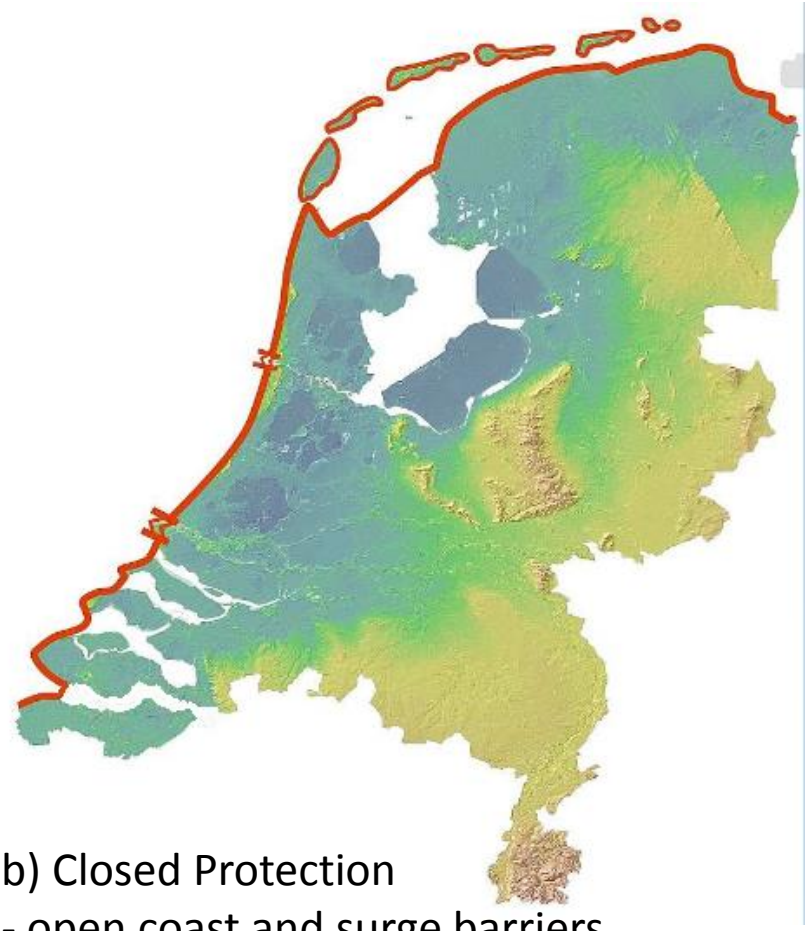
Defence technologies, approaches and adaptation strategies

Defence Technologies	(1) Sea dikes (updated costs based on Jonkman et al., 2013)
	(2) River dikes (updated costs based on Jonkman et al., 2013)
	(3) Surge barriers (costs from Jonkman et al., 2013 and Mooyaart and Jonkman, 2017)
Defence Approaches	(1) Dike only protection (not considered here)
	(2) Dike and barrier protection
Adaptation Strategies	(1) Constant Protection Levels -- maintain current protection levels
	(2) Constant Absolute Flood Risk -- maintain average losses
	(3) Constant Relative Flood Risk -- maintain relative losses
	(4) Risk Intolerance -- keep relative losses below 0.01% percent of local GDP

Different protection choices



(a) Open Protection
-- open coast and river dikes



(b) Closed Protection
-- open coast and surge barriers
(and closure dams)

Protection standards

(following Sadoff et al., 2015 [Securing Water, Sustaining Growth])

Wealth Class (annual income per capita) (2014 US$ GDP per capita (PPP))	Urban (>1000 people/km^2)	Rural (30 to 1000 people/km^2)	Uninhabited (<30 people/km^2)
Low income	1:10	none	none
Lower middle income	1:25	none	none
Upper middle income	1:100	1:20	none
High income	1:200	1:50	none
Special case: Netherlands	1:10,000		
Special case: 136 large coastal cities	from Hallegatte et al. (2013)		

Scenarios

SSP2 and RCP2.6/RCP8.5

Year		2015	2030	2050	2075	2100
Global population (billions)		7.4	8.4	9.4	9.7	9.2
GDP per capita (US$, global average)		14,400	20,800	30,000	46,700	72,600
Sea-level rise, (global coastal average, m)	RCP 2.6	0.03	0.08	0.14	0.21	0.28
	RCP 8.5	0.03	0.09	0.19	0.39	0.65

Note: Base year for sea-level rise is 1985 to 2005 average

Results

All for dike and barrier protection

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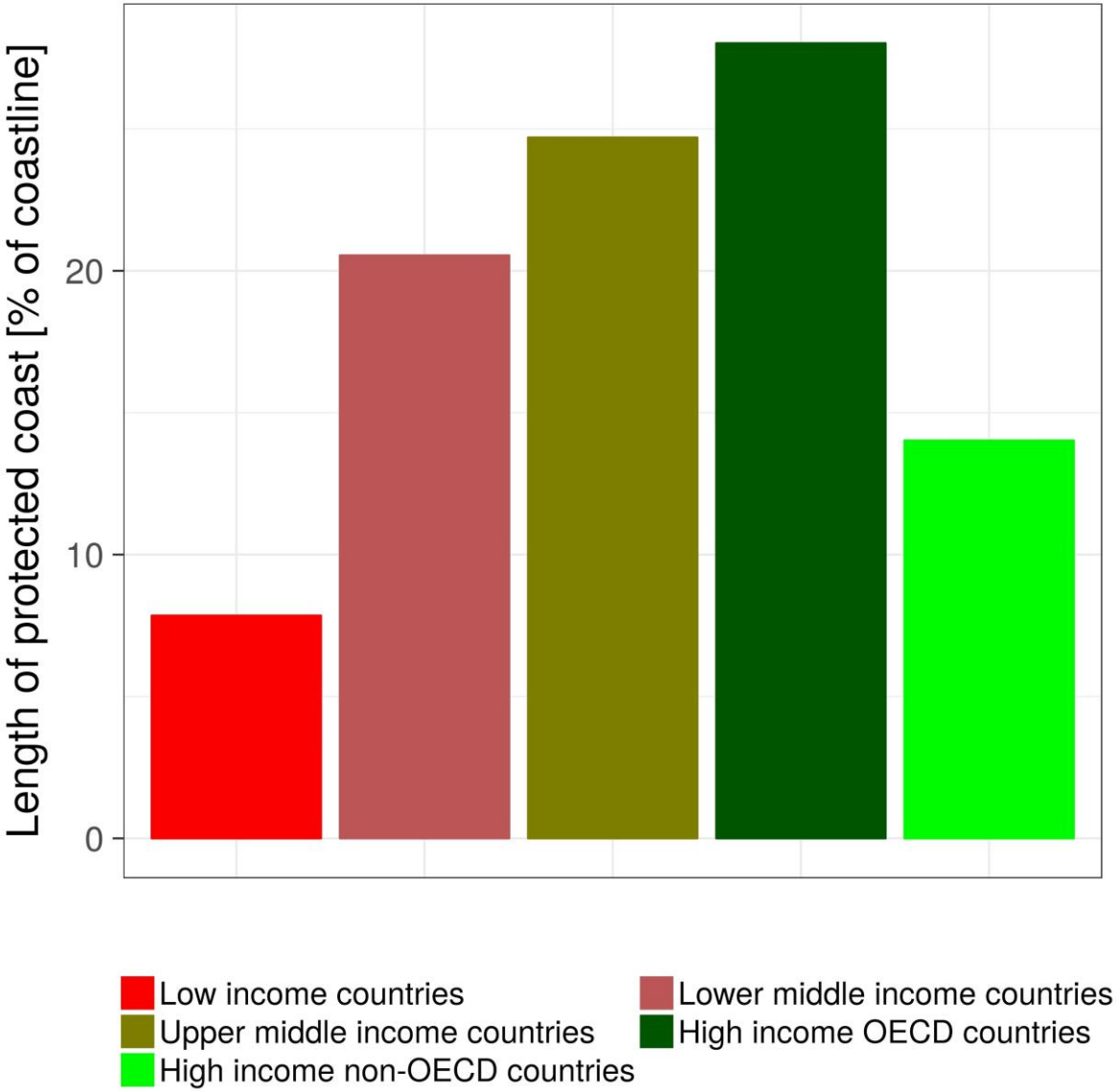
Length of protected open coast

By country groups in 2015



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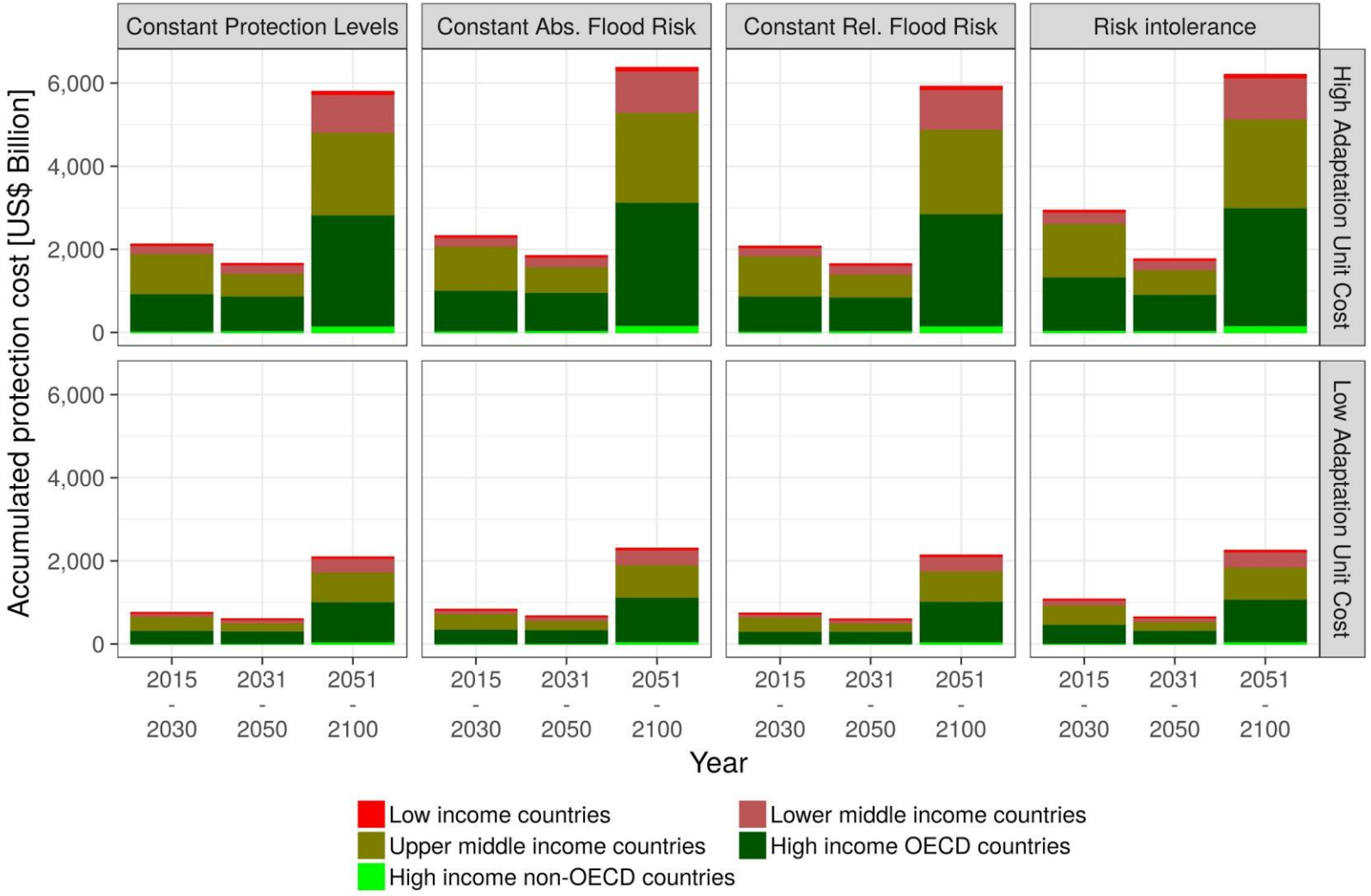
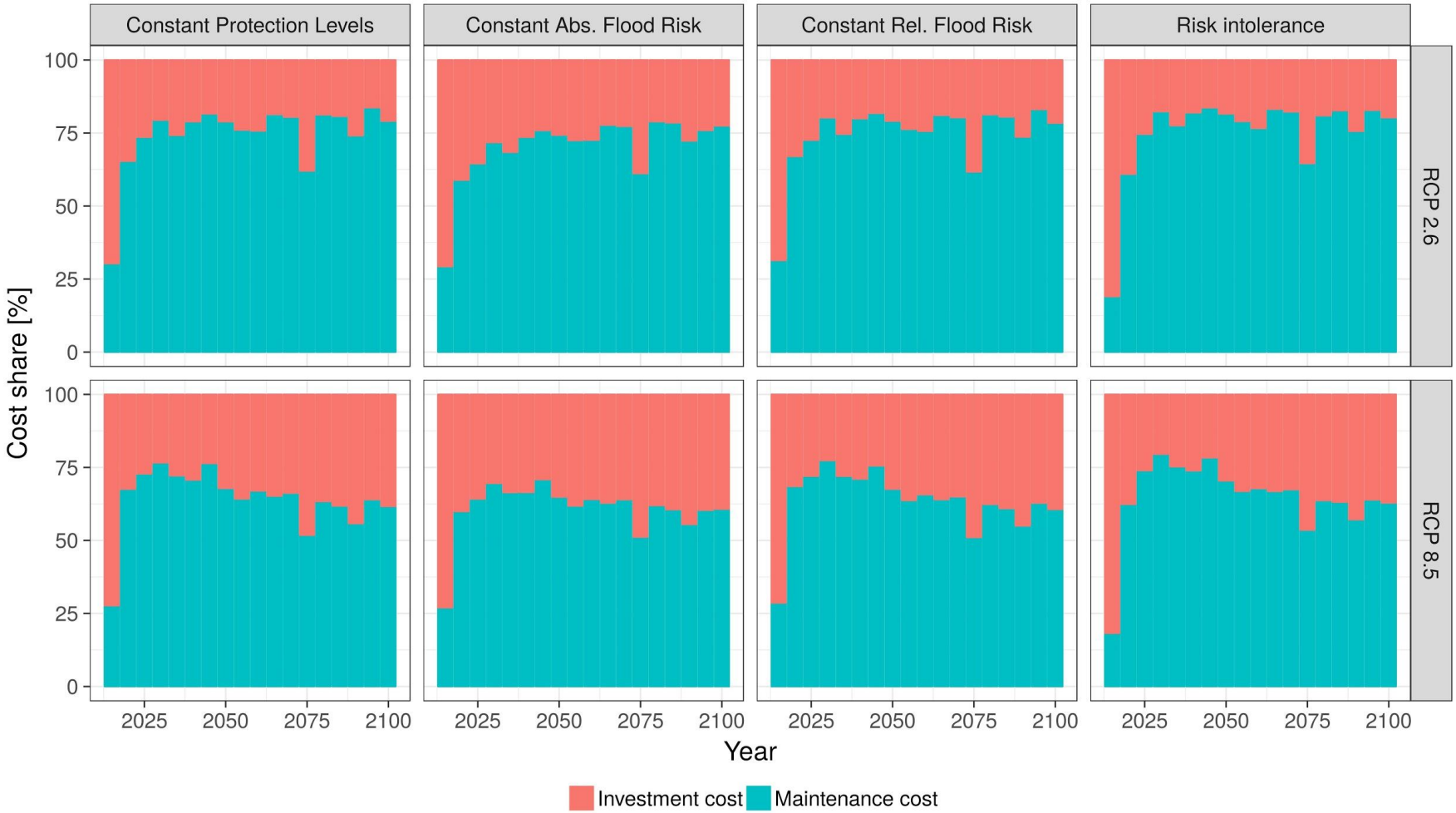
Protection costs, 2015-2030, 2031-2050, 2051-2100

RCP8.5 sea-level rise scenario

Sums maintenance and capital costs



Capital versus maintenance costs



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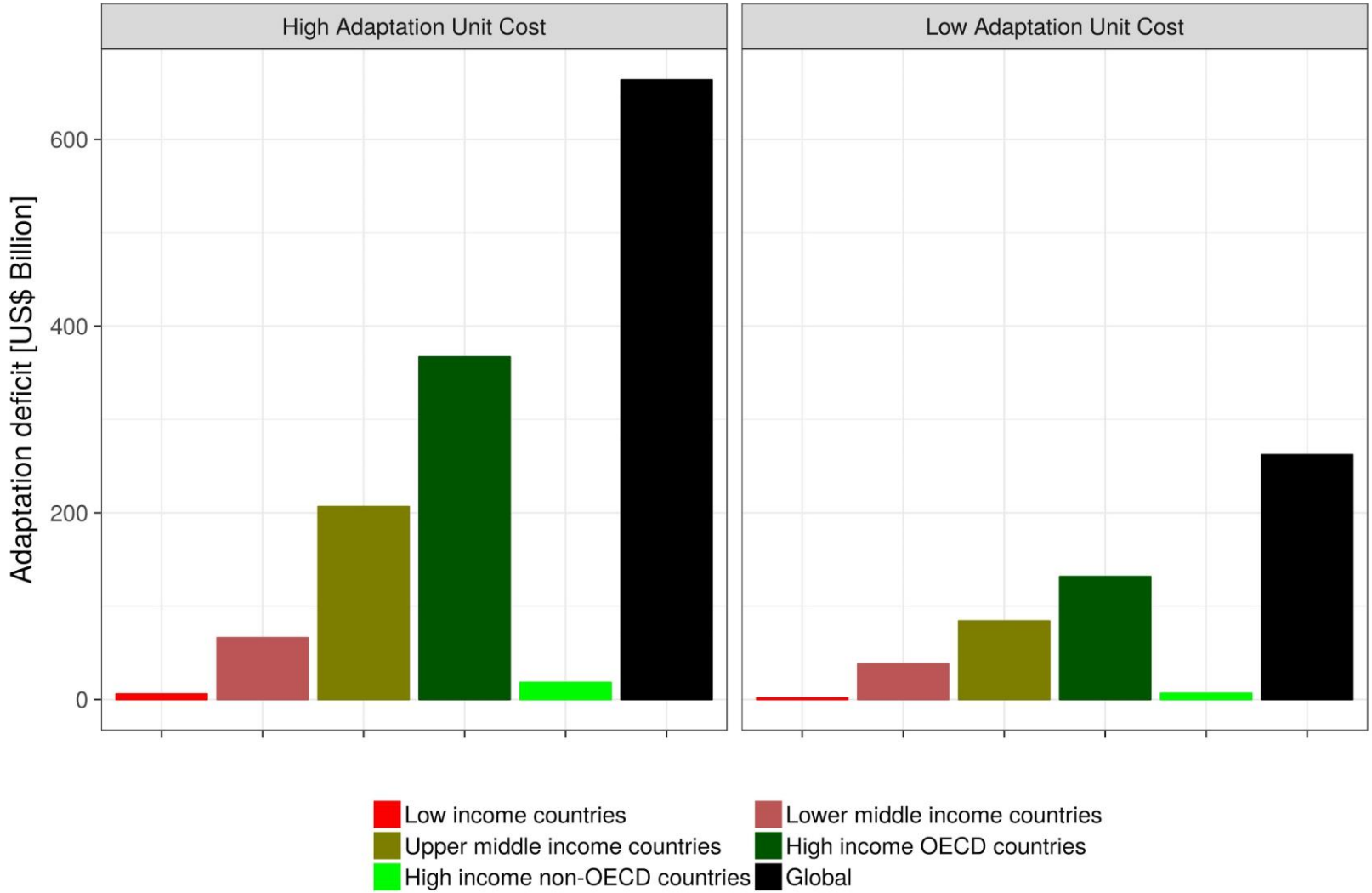
Adaptation deficit, 2015

Comparing the Constant Protection and Risk Intolerance Strategies, includes maintenance and capital costs



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Summary of Costs

Cost Components	RCP2.6		RCP8.5	
Capital Costs Sea Dikes	0.67-1.85	24%	1.17-3.21	34%
Maintenance Costs Sea Dikes	1.93-5.32	70%	2.07-5.70	60%
Maintenance Costs Sea Dikes (built since 2015)	(0.39-1.08)	14%	(0.53-1.47)	15%
Maintenance Costs Sea Dikes (built before 2015)	(1.54-4.24)	56%	(1.54-4.23)	45%
Capital Costs River Defences	0.11-0.36	4%/5%	0.16-0.50	5%
Maintenance Costs River Defences	0.04-0.14	1%/2%	0.05-0.15	1%/2%
TOTAL COSTS Constant Level Protection	2.76-7.67		3.44-9.56	
Adaptation Deficit in 2015	0.23-0.67	8%/9%	0.26-0.66	7%/8%
Additional Costs from 2020 to 2100	0.44-1.24	16%	0.52-1.33	14%/15%
TOTAL COSTS Risk Intolerant Protection	3.20-8.90		3.96-10.90	

Concluding Thoughts (1)

- These new defence costs are higher than earlier estimates, mainly reflecting: (1) higher range of unit defence costs; and (2) consideration of maintenance of the existing dike stock (in 2015).
- For the Constant Protection Strategy, the total accumulated defence costs from 2015 to 2100 are up to US$7.7 trillion and US$9.6 trillion for the RCP2.6 and RCP8.5 scenarios, respectively.
- Open coast defences dominate protection costs.
- Maintenance costs are larger than capital costs.
- Risk Intolerant Protection Strategy raises costs by about 15% over the century compared to the Constant Protection Level Strategy.
- This is a first estimate of the adaptation deficit, but strongly dependent on the baseline assumption, so much further investigation required.
- Most protection occurs in High Income OECD countries and Upper Middle Income Countries.
- While the absolute costs are high, they are small compared to potential damages – in benefit-cost terms they are widely justifiable.

Concluding Thoughts (2)

- There are more defence options than dikes and barriers – what is presented is stylised (and there are other adaptation options).
- There are downsides to a defence (or protect) strategy.
- The world's developed coast will increasingly resemble the Netherlands – growing flood plains and potential damage and threat to life if defences fail.
- Sea-level rise continues after 2100 for many centuries (there is a commitment to sea-level rise and adaptation to sea-level rise).
- Residual risk must be considered and managed which implies ongoing investment in flood simulation, forecasting and warning.
- Delivering maintenance implies significant efforts to enhance flood management and governance institutions.
- Future analyses could useful focus on benefit-cost analysis and empirical data collection on defence baselines and costs.

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