Cost evaluation of multi-sector adaptation pathways: A case for nature-based adaptation strategies

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1. Research Purpose

Climate change already affects local communities, and these impacts are projected to become more severe and intense in the future (IPCC, 2012). Benefits of implementing climate adaptation at the local level have been widely recognized with increased numbers of adaptation planning support tools provided by various actors (ICLEI, 2010; Giordano et al., 2013). However climate change demands a long-term perspective, traditional values and priorities in planning are challenged, and the responsibility to take action is ambiguous. The aim of this study is to first develop a planning model that can determine a pareto of optimal plans to maximize the multi-sector benefits and second to evaluate the costs of plans with nature-based strategies against the alternative.

Rather than fixing the budget constraint or the adaptation goal, this model is able to provide real-time simulation of optimal plans depending on the user's needs and uncertainties. By developing this model into a user interface, the usability of this method in planning for adaptation will be evaluated by actual policy practitioners. Benchmarking this case study and methodology, decision-makers will be able to actively engage in developing their adaptation pathway.

2. Innovative Adaptation Planning Frameworks

A recent suggested strategy is using the concept of "adaptation pathways(AP)" to systematically and dynamically sequence adaptation solutions across a long time-frame (Haasnoot et al., 2013; Kwakkel et al., 2016), where each pathway represents an alternative plan. A sequential approach can realistically consider the short-term constraints with a goal-oriented long term perspective.

Recent studies on adaptation to climate change are increasing the quantification of additional and functional effects of various green infrastructure technologies (Mullaney et al., 2015; Zölch et al., 2016). Nature-based adaptation reduces the impact of climate change by reinforcing natural systems in a concept similar to green infrastructure, and appears to be more environmentally-friendly, sustainable and sometimes more cost-effective than structure-based adaptation technologies. The nature-based technologies considered in this study are limited to roadside trees, grass planting and wall greening.

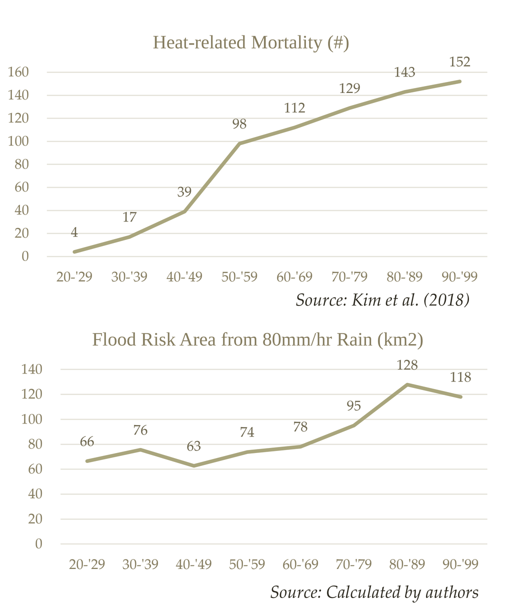
This study differs from past research and traditional planning models in the following aspects:

- Adaptation pathways have not been able to consider the synergies and trade-off of different sectors by incorporating them into a single planning model
- Method is adjustable to different spatiotemporal scales for future studies

3. Study Scope and Input Data

- Seoul, South Korea was selected as a reference site based on the its heat and urban flooding vulnerabilities
  - Urban heat island: low rise buildings wide street walks
  - Flooding: large watershed (potential for flood based on DEM, drainage line, etc) and past flooding record
  - Vulnerable populations – children and elderly
- Planning time horizon was set to 2020~2100, to which 8 adaptation technologies were evaluated and future climate impacts were modeled using HadGEM2 RCP 8.5 scenario by the Korea Meteorological Administration (KMA)
- The following inputs were used to search for optimal Adaptation Pathways

Climate Impacts



Evaluation of Adaptation Technologies

Name	Description	Size	Effect	Unit	Cost($1,000)	Source	Illustration
Pavement Sprinkle (H1)	Water sprinkling of 1km street per day	~4000	0.056*H1	Reduced Mortality	731	Yang et al . (2019)	
Heat Warning Text Alarm (H2)	1 alarm text to all citizens	~400	0.11*H2		1520		
Cooling Center (H3)	Management personnel's visit and maintenance of cooling center	~25	0.7*H3		1600		
Street tree (G1)	Plant 1 street tree with height = 7 m, can opy width = 4 m	~100	0.6345*U1	Reduced MRT (ºC) -> heat related mortality	10400	Park et al. (2019)	
Green wall (G2)	Convert a building wall into a green wal 1 with grass height = 0.3 m	~50	0.77ln(U2+1)		6225		
Greenway sidewalk (G3)	Convert a 150m² stretch of sidewalk into grass with grass height = 0.3 m	~200	0.77ln(U3+1) 0.52ln(F1+1)		750		
Rain Barrels (W1)	Construct in basement under schools and buildings higher than 8 floors	~100	1*F2	Flooded area (m²)	10450	Choi et al. (2019)	
Basins (W2)	Construct basin under parks located at critical drainage lines	~8	1*F3		22700		

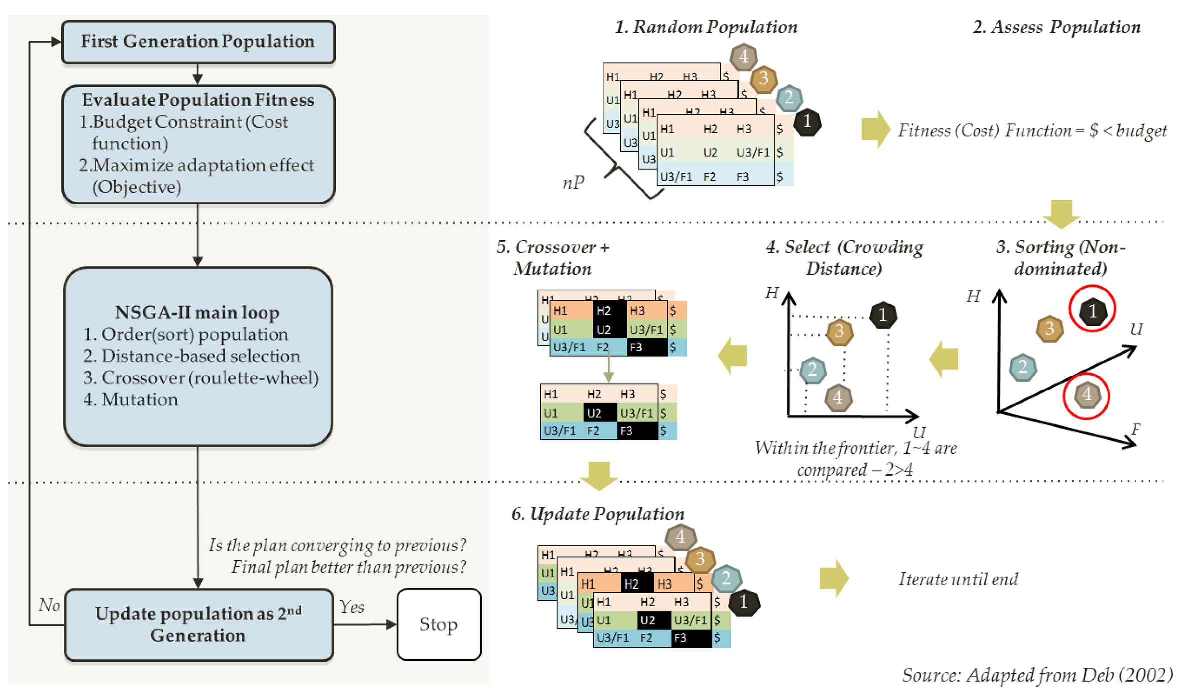
Constraints

10 year budget constraints and reaching minimum impact reduction targets

4. Application of Multi-objective Optimization Method

Optimization was conducted using a non-dominated sorting algorithm (NSGA-II) where optimality of plans were determined by two decision variables – total adaptation effect (reducing flooding and heat-related moralities) and cost. The cost of APs were calculated as below using NPV.

$$\mathrm{NPV}_a = \left[\frac{C_{i,k}}{(1+r)^{t_d}} + \sum_{t=1,k=1}^{t_d,K}\left(\frac{C_{t,k}}{(1+r)^t}\right)\right] + \left[\frac{C_{i,k}}{(1+r)^{T-t_d}} + \sum_{t=t_d,k=1}^{T,K}\left(\frac{C_{t,k}}{(1+r)^t}\right)\right]$$

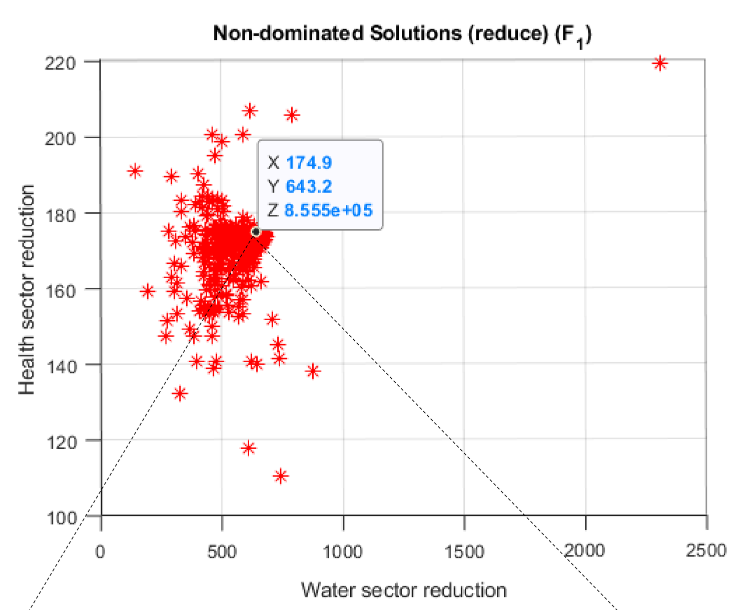


5. Adaptation Pathway Optimization Results

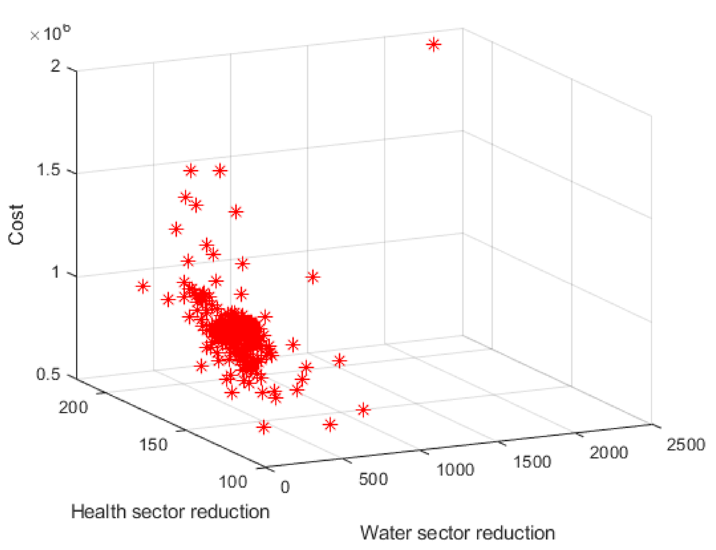
Adaptation Pathways with Nature-based Strategies

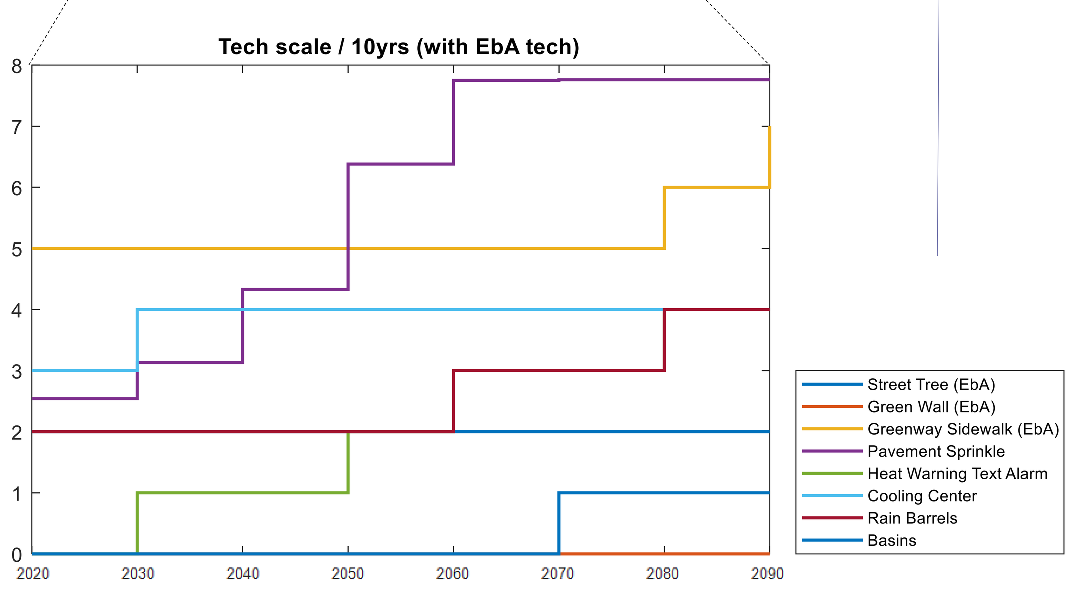
Adaptation pathways were optimized for 1000 iterations (results are shown below) and resulted in a pareto of 100 APs as shown on the right. X-axis indicates the total reduction of flooding induced damage area (km2) and the y-axis indicates the heat related mortality. The z-axis is the NPV cost of the entire AP.

The detailed drawing of a sample adaptation pathway shows the number of each adaptation technology to be invested each 10 year planning interval.

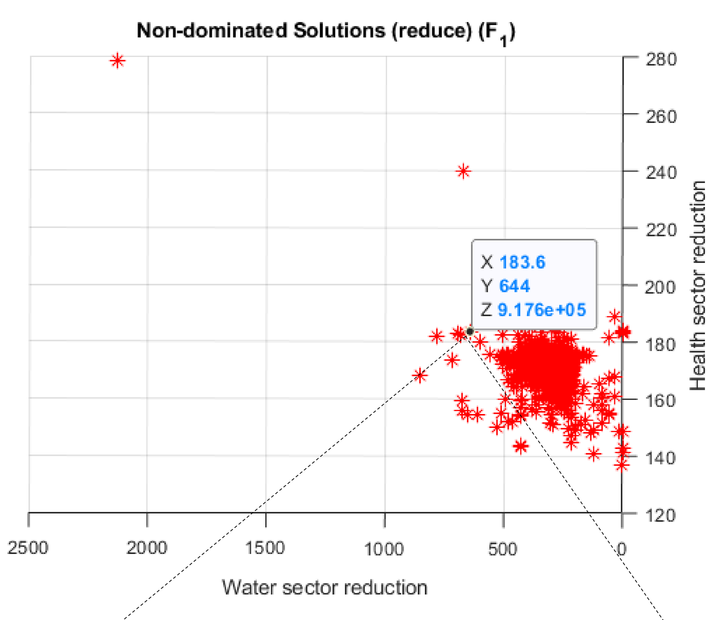


1000 iterations of optimizing 100 AP sets

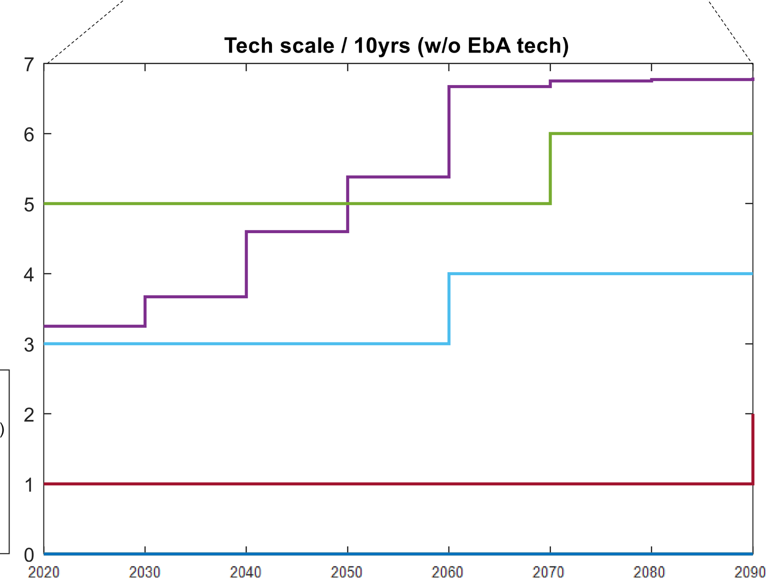




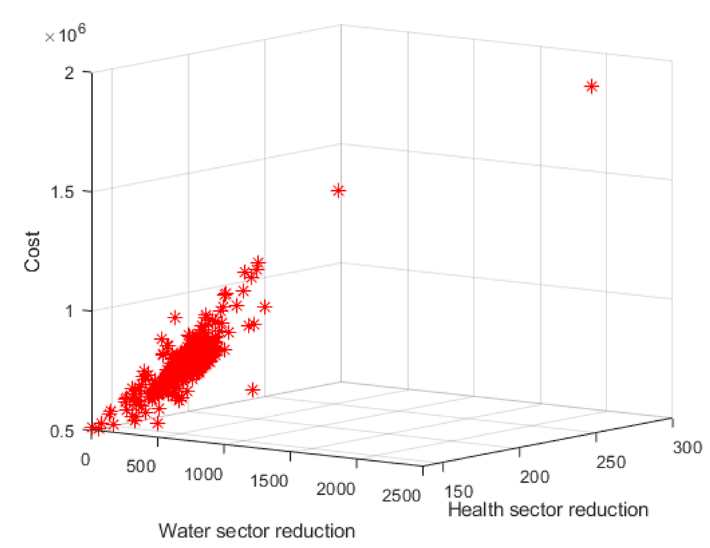
Adaptation Pathways without Nature-based Strategies



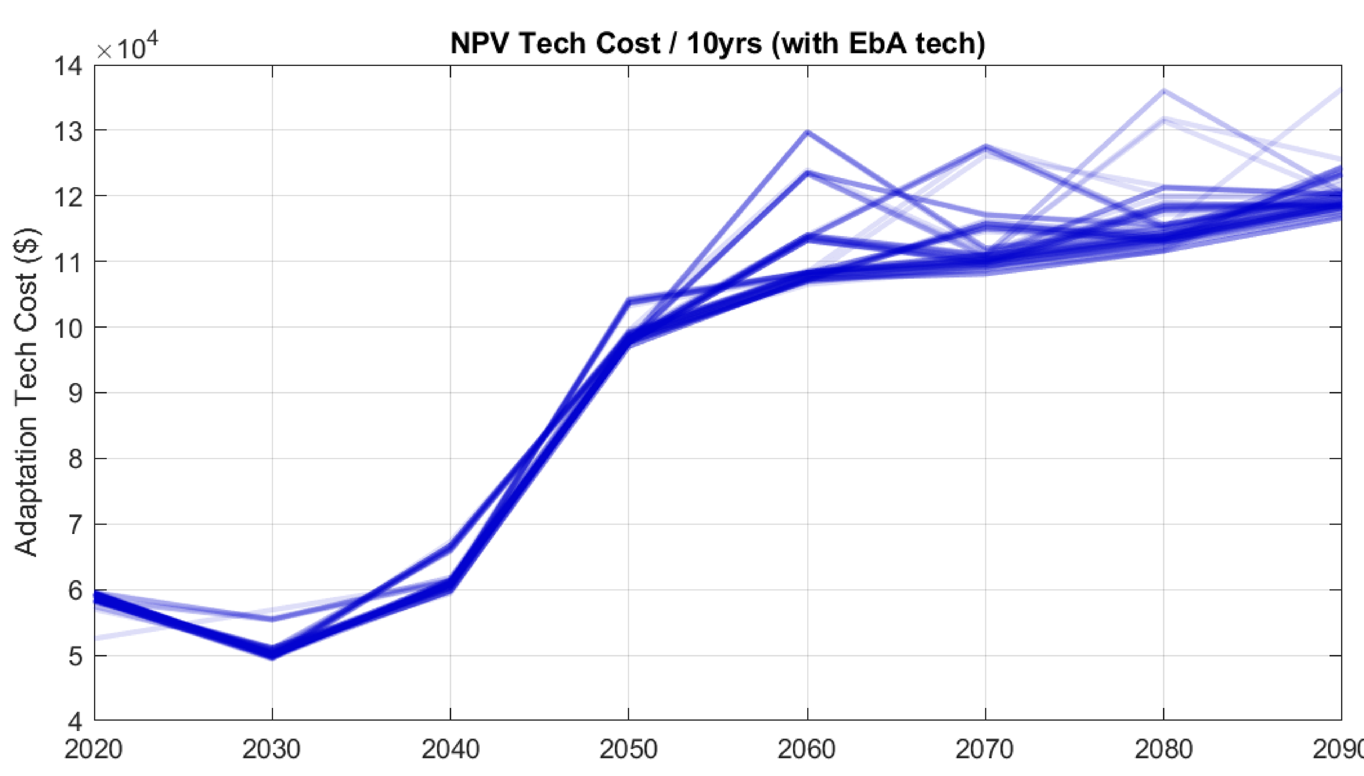
Pathway with and without nature-based strategies showed significant difference in what technologies, and to what scale, were selected into the plans. Pathways with nature-based solutions included fewer and delayed investments of traditional grey infrastructure technologies.

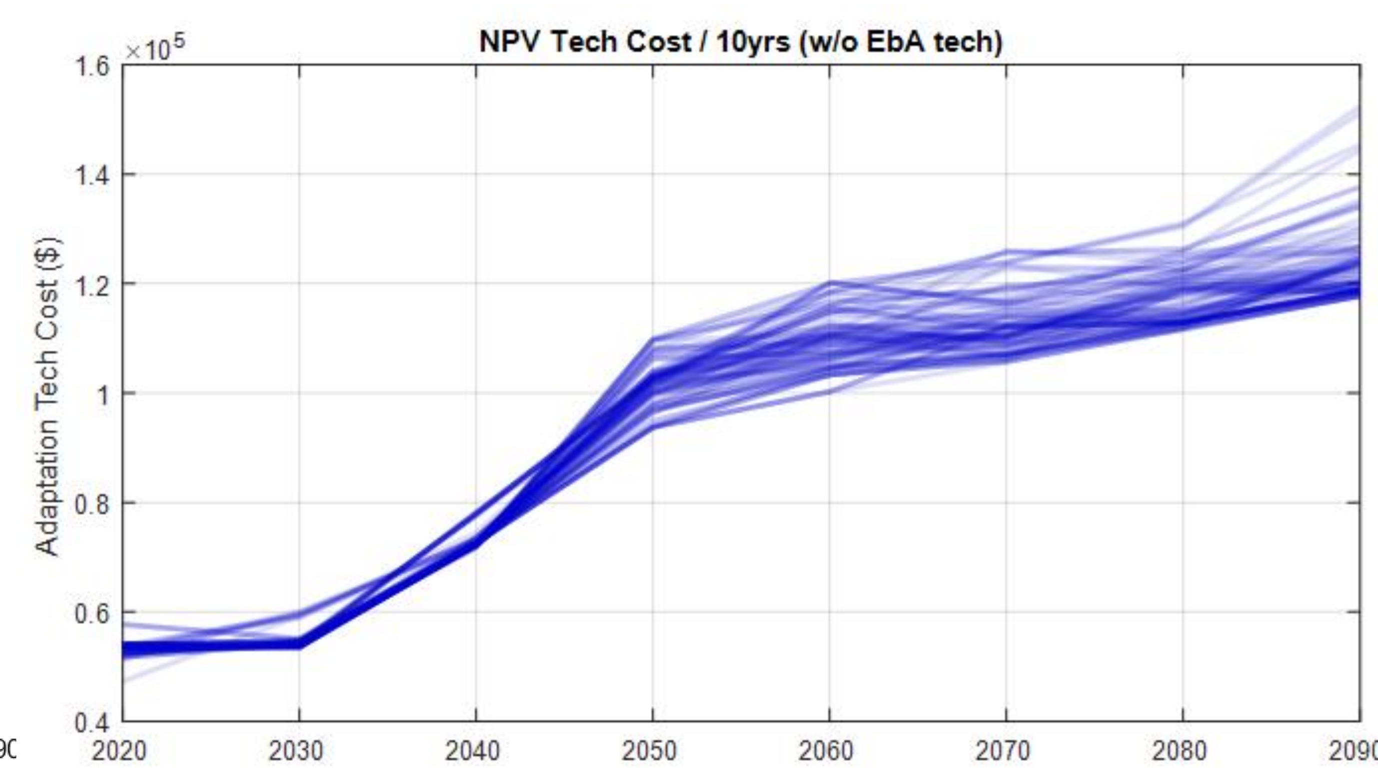


1000 iterations of optimizing 100 AP sets



6. Cost Evaluation of Adaptation Pathway with and without Nature-based Strategies





The benefits of nature-based strategies are realized directly (in terms of cost-benefit) as they serve as buffers to delay and partially reduce the investment of grey infrastructure. The cost of APs is much more varied for those including nature-based strategies as a result of the trade-offs in investing in the alternatives. In both scenarios a noticeable drop in NPVs from the pathway is shown around 2030 – this drop can be defined as an "investment tipping point" where an inefficient investment in time of the initial strategy, though later in time will reach economic efficiency, occurs. (L.T. de Ruig et al., 2019) The two figures ultimately show that APs were cost-optimized and that nature-based adaptation strategies are a cost-effective alternative to traditional measures

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