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Methods and decision-making for investments to deal with disruptions

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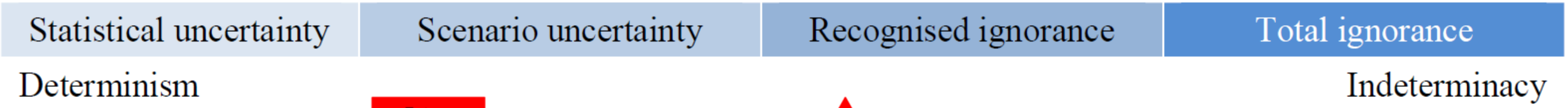
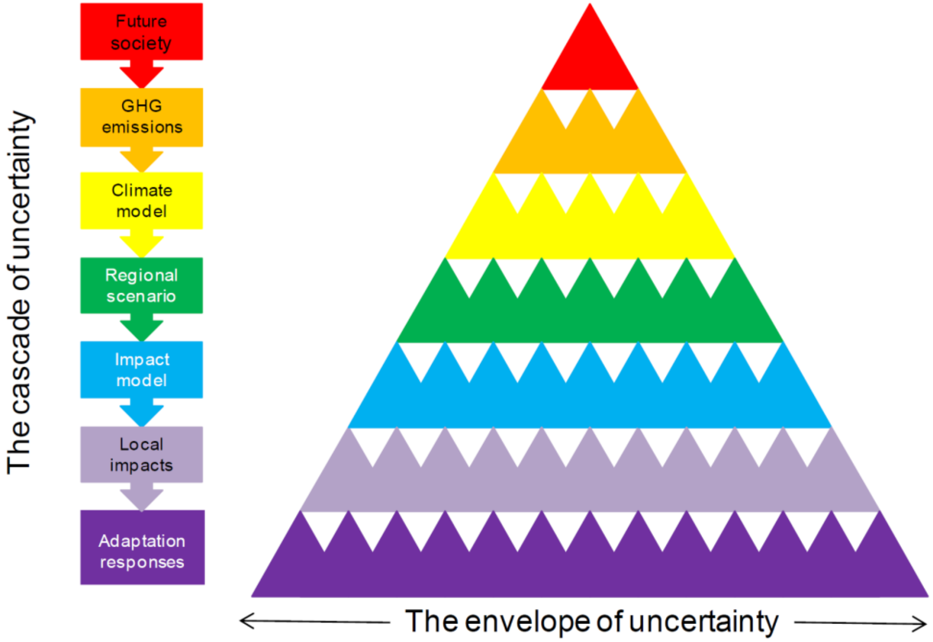
Levels of uncertainty

Walker et al. (2003)





Wilby & Dessai (2010)

Three themes for robust decision-making

Principle 1: Embrace uncertainties

- Start from the real uncertainties and adapt the decision-making processes and the methods to deal with those types of uncertainties that we are really facing

Principle 2: Start with the decision situation

- Start with the specific decision situation and research the consequences of different options
- Then collect more information for the uncertain factors that are particular relevant to the current decision

Principle 3: Seek robust solutions

- Try to find robust solutions that work well over one large number of uncertain outcomes. Be open to new types of solutions.
- Is it possible, for example, to remove the vulnerability for the uncertainties in a simple or cheap way? Is it possible to find solutions that are flexible and can be adapted over time?

Wikman-Svahn (2016)

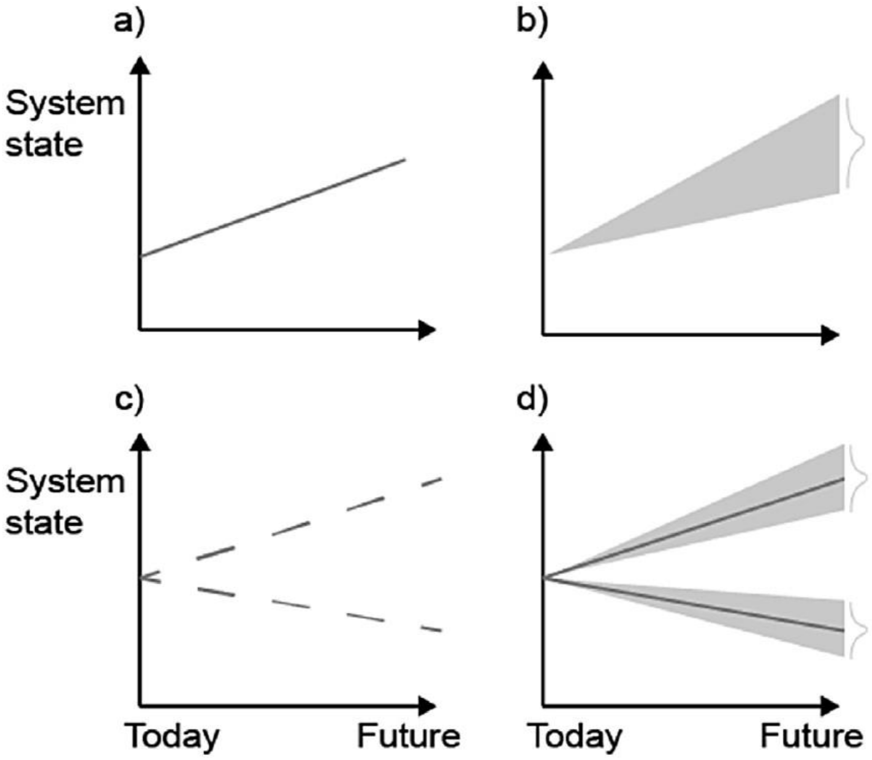
Embracing uncertainties: Future modeling paradigms

a) anticipating the future based on best available knowledge

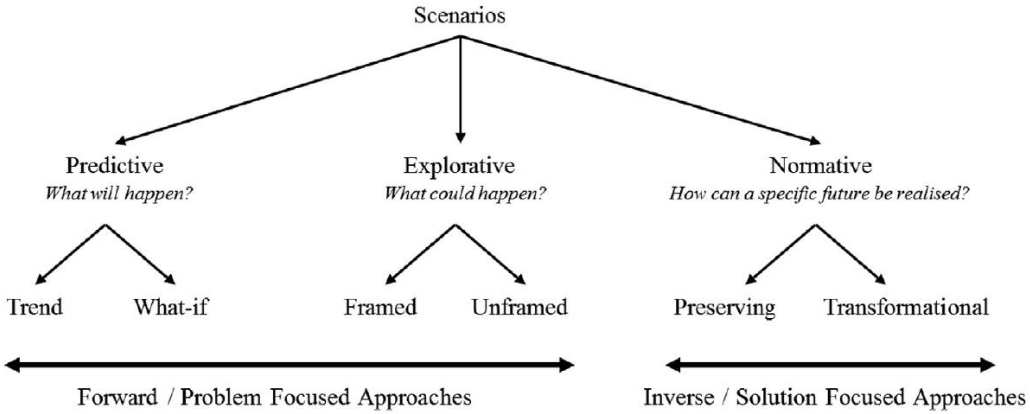
b) quantifying future uncertainty

c) exploring multiple plausible futures

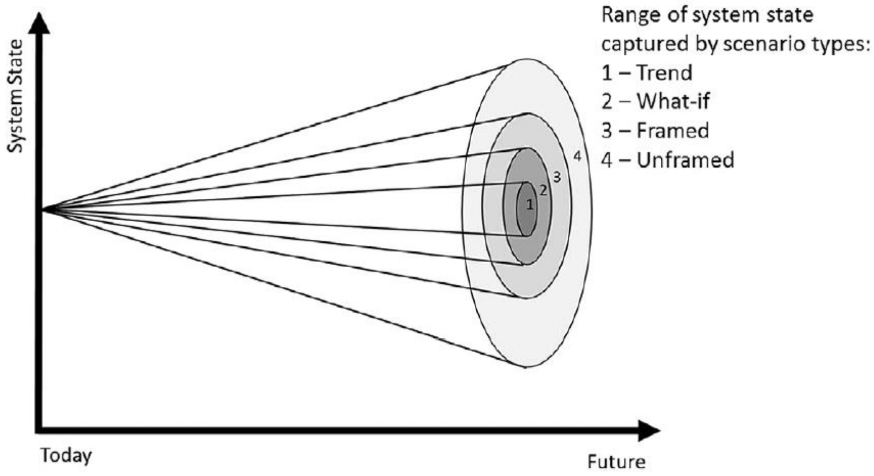
d) combining the three paradigms to address different sources of uncertainty within a problem



Identifying multiple plausible futures



Maier et al. (2016) after Börjeson et al. (2006)



Maier et al. (2016)

Methods for decision-making under uncertainty

Tool	Strengths	Weaknesses	Most useful when
Cost-benefit analysis	Provides direct analysis of economic, benefits, justification for action, and optimal solutions. Well known and widely applied.	Difficulty of monetary valuation for non-market sectors and non-technical options. Uncertainty usually limited to probabilistic risks.	Climate probabilities known. Climate sensitivity small compared to costs/benefits. Good data exists for major cost/benefit components.
Cost-effectiveness analysis	Benefits expressed in physical terms (not monetary) thus applicable to non-market sectors. Relatively simple to apply and easily understandable ranking and outputs. Use of cost curves can assess policy targets with least-cost optimisation. Used for mitigation, thus widely recognised and resonance with policy makers.	Benefits can be difficult to identify and single metric does not capture all costs and benefits. Less applicable cross-sectoral/complex risks. Works best with technical options, and often omits capacity building and soft measures. Sequential nature of cost curves ignores interlinkages and potential for portfolios. Does not lend itself to the consideration of uncertainty, as works with central tendency.	Same as CBA, but for nonmonetary metrics. Agreement on sectoral social objective (e.g. acceptable risks of flooding).
Multi-criteria analysis	Combines quantitative and qualitative data,; monetary and non-monetary units, thus applicable where quantification is challenging. Relatively simple and transparent, and relatively low cost/time requirement. Expert judgement can be used very efficiently, and involves stakeholders, thus can be based on local knowledge.	Results need further interpretation and elaboration in more detailed studies. Different experts may have different opinions, i.e. subjectivity involved. Stakeholders may lack knowledge and can miss important options. Analysis of uncertainty is often qualitative and subjective.	Mix of qualitative and quantification data.

Tool	Strengths	Weaknesses	Most useful when
Real-options analysis	Assesses value of flexibility and learning, in quantitative and economic terms. Decision trees conceptualise and visualise the concept of adaptive management.	Data and resource intensive, with high complexity and expert input. Data a potential barrier, (probabilistic climate, quantitative and economic information). Identification decision points often complex.	Large irreversible capital decisions. Climate risk probabilities known or good information. - Good quality data for major cost/benefit components.
Robust decision making	Assesses robustness rather than optimisation. Applicable where probabilistic information is low or missing, or climate uncertainty is high. Can work with physical or economic metrics, enhancing application across sectors.	Lack of quantitative probabilities can make more subjective, influenced by stakeholders. The formal application has a high demand for quantitative information, computing power, and requires a high degree of expert knowledge.	High uncertainty of climate change signal. Mix of quantitative and qualitative information. Non-market sectors (e.g. ecosystems, health).
Portfolio analysis	Assesses portfolios, which analysis of individual adaptation options not allow. Measures “returns” using various metrics, including physical or economic, thus broad applicability. Use of the efficiency frontier an effective way of visualising results and risk-return trade-offs.	Resource intensive and needs expert knowledge. Relies on the availability of quantitative data (effectiveness and variance/co-variance). Requires probabilistic climate information, or an assumption of likelihood equivalence. Issues of inter-dependence between options.	Adaptation actions likely to be complementary in reducing climate risks. Climate risk probabilities known or good information.

ITF (2016)

Cost-benefit analysis (Swedish standard ASEK 7.1)

- For preventive measures that involve climate adaptation of the infrastructure, socio-economic profitability is determined by the cost of the measure in relation to the savings in expected future damage costs that the measure leads to
- Saved expected future damage costs are determined by the reduced risk of damage that the measure entails and the socio-economic cost of the effects that the damage to the infrastructure leads to

Cost-benefit analysis (Swedish standard ASEK 7.1)

- Investment calculation:

$$NPV = GPV - I = \sum_t Df_t \cdot E(C_t) - I$$

- NPV: Sum net present value
- GPV: Sum gross present value, i.e., sum present value of future effects
- Df_t: Discounting factor for calculating present value of expected changes in damage costs year t
- $E(C_t)$: Statistical expectaction of saved damage cost year t (cost difference with/without action)
- I: Investment cost for action that reduces risk of infrastructure damage

- $E(C_t) = Prob_{1t} \cdot C_{1t} + Prob_{2t} \cdot C_{2t} + \cdots + Prob_{nt} \cdot C_{nt}$
- $Prob_{it}$: Probability that certain cost, C_{it}, occurs year t, $\sum_i Prob_{it} = 1$

Start with decision situation
Top-bottom and bottom-top approaches

A **top-down process** starts by making scientific assessments of the factors that may influence the system, which are then used as an input for the decision

- Identifies potential risks and then evaluates management responses (Jones et al. 2014)
- Example of a typical top-down process involves starting with the results from global climate models, downscaling these to the geographical area of interest and using these as a baseline for decision making
- Other terms include “science first”, “predict then act” and “scenario led” (Lempert et al. 2004; Wilby and Dessai 2010; Jones et al. 2014)

Wikman-Svahn (2016)

Start with decision situation
Top-bottom and bottom-top approaches

- A **bottom-up process** starts from decision-making context by identifying relevant vulnerabilities, potential solutions and critical tipping-points when solutions fail
- Some assessment of relevant uncertainties is needed in bottom-up processes, but this has less weight at start of process, and is instead refined iteratively throughout
- Bottom-up processes have also been called “assess-risk-of-policy framing”, “policy-first” or “tipping-point” approaches

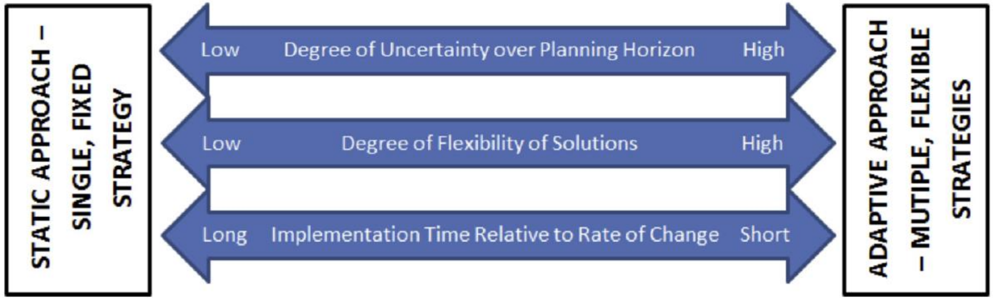
- While top-down processes could also be used to find robust decisions, literature typically recommends bottom-up processes when the uncertainties are severe or deep
- Advantage: change the focus
  - from having to agree on difficult and controversial assessments of future developments,
  - to actual decision to be made and finding potential solutions

Wikman-Svahn (2016)

Seek robust solutions
Static and adaptive approaches

- A **static approach** is a predetermined strategy that works satisfactorily under the full range of uncertain outcomes
- Example: To protect critical infrastructure site, such as bridge, against flooding from high sea levels would be to build bridge fundaments sufficiently high above mean sea level (with a safety margin) so that it is extremely unlikely to be flooded during its lifetime
- A **flexible approach** consists of several different options for different future circumstances, and a switch can be made between the options, depending on how the future unfolds

Wikman-Svahn (2016)



Maier et al. (2016)

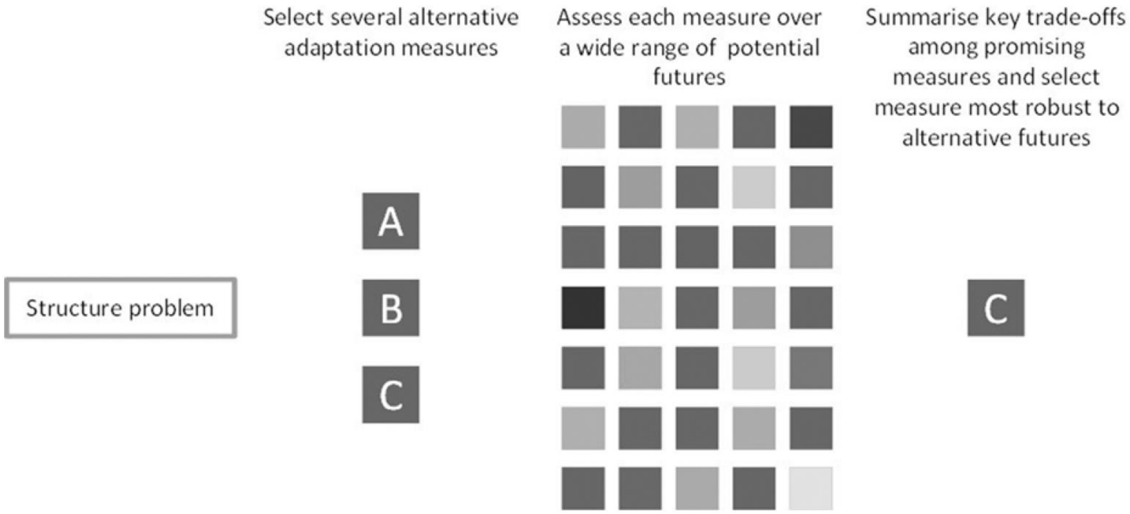
Seek robust solutions
Static and adaptive approaches

- Adaptive approaches can either be **static** or **dynamic**
- As part of **static adaptive** approaches,
  - basic policy remains fixed and contingency actions are taken to stay on course,
  - or a set of adaptive pathways remains fixed over the length of the planning horizon, although there are opportunities to move between them
- As part of **dynamic adaptive** approaches,
  the actual pathways can also change over time as new knowledge about future states of the world becomes available
- Dynamic or adaptive approaches require the use of time series or transient scenarios, describing changing conditions over time

Maier et al. (2016)

Robust decision-making

- Robust decision support approaches include both quantitative statistical methods, qualitative methods and 'light versions' of these



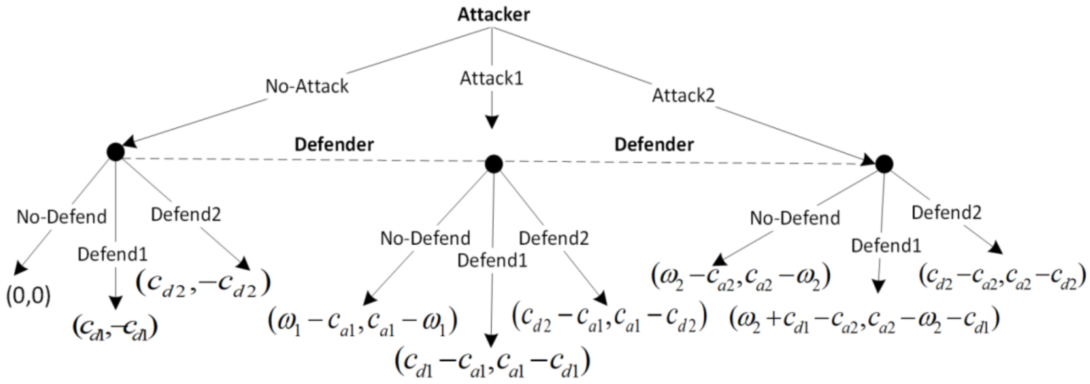
ITF (2016) after Groves et al. (2008)

Worst-case analysis

- Decision-making against worst possible scenario
- Vulnerability analysis: Identify most critical system components / scenarios

Jenelius and Mattsson (2021)

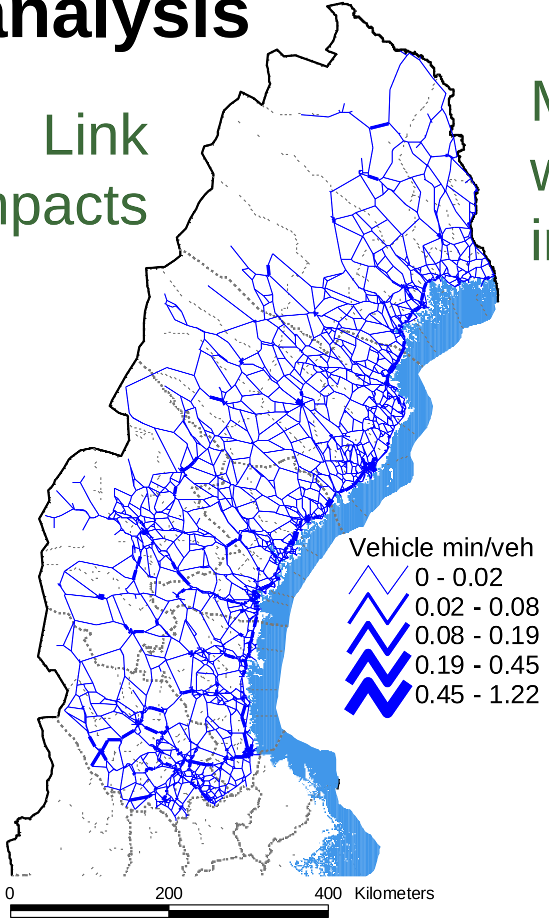
- Antagonisitic threats: Likelihood of scenario realizations depend on decision
- **Game theory**: Strategies against a rational opponent



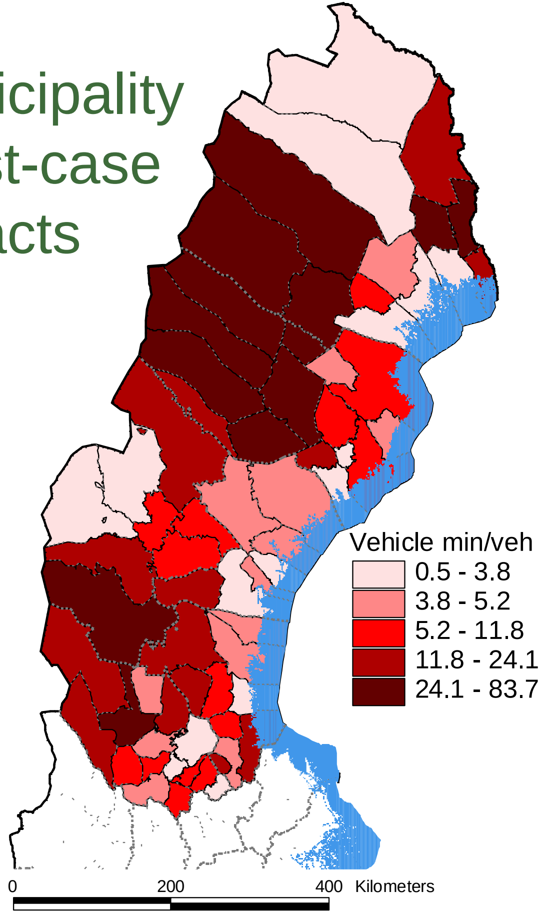
Attiah et al. (2018)

Worst-case analysis

Link closure impacts



Municipality worst-case impacts



Jenelius et al. (2006)

Examples from Sweden
Adapation to future sea-water rise

- Carlsson Kanyama et al. (2019) studied five decision-making processes
  - Three local level (municipalities), one regional, one national

1) How were uncertainties in climate change handled?
2) To what extent were bottom-up approaches used?
3) Did the organizations aim for robust strategies (either static or flexible)?

Examples from Sweden
Adapation to future sea-water rise

Organisation	How uncertainties were handled	The use of bottom-up approaches	The use of static versus flexible solutions
The Swedish Transport Administration	The administration made an assumption of a reasonable sea level rise by 2100 based on SMHI's estimate and added an "uncertainty margin" to this level.	A top-down approach was used in which the future climate was a starting point in the planning process. In the next step, possible consequences of the future climate were described for the infrastructure studied. Finally, possible adaption measures were identified.	Flexible solutions were chosen with measures identified for three different levels of the sea. Future measures were prepared, for example by reservation of land when needed.
Swedish Nuclear Fuel and Waste Management Company	The company made its own assessment of a *maximum* global sea level rise by 2100 and did not rely only on information from SMHI.	Same as above.	A static solution was chosen on where to lay the foundation level of the surface facility. It was planned at such a height that it can handle the most extreme scenario of future sea level rise.
City of Gothenburg	The municipality acted much in the same way as the Swedish Transport Administration by making its own estimation of sea level rise based on scientific literature and by adding a security margin.	Same as above.	The city has a planning directive for the lowest level of the grounds of new buildings. Besides that, flexible solutions were chosen, such as preparing to raise the street level and the floor of the buildings in case of need in the future. Also, solutions on a larger scale were planned for long-term management of flood risks.
Haninge municipality	The municipality asked for, and was provided with, one planning level describing a reasonable future sea level rise. No uncertainties in this level were considered.	Same as above.	Static solutions were chosen on where to locate new houses. That means that new houses should not be built less than 2.7 meters below the present sea level. No further adaptation measure were thought to be needed.
Nacka municipality	Same as above.	Same as above.	Same as above.

Examples from Sweden
Adapation to future sea-water rise

- Discrepancy between current approaches and the core principles of robust decision support approaches.
- Typically
  - do not embrace uncertainties
  - do not use a bottom-up approach
  - do not aim for robustness (but used both static and flexible strategies)

Carlsson Kanyama et al. (2019)

Examples from Sweden
Adapation to future sea-water rise

- Three main barriers for introducing robust decision support approaches to handle climate change uncertainties in the future:

1) The whole setup of climate change adaptation in Sweden today relies on a top-down approach
2) The process of delivering climate information needs to be changed
   - The defined worst-case scenario may not consider full uncertainty
3) Using robust decision support approaches would be more time consuming, both at the local and regional levels

Carlsson Kanyama et al. (2019)

References

- Attiah, A. et al. (2018) A game theoretic approach to model cyber attack and defense strategies. *2018 IEEE International Conference on Communications (ICC)*, Kansas City, MO, USA, 2018, pp. 1-7.
- Börjeson, L. et al. (2006) Scenario types and techniques: towards a user's guide. *Futures* 38(7), 723-739.
- Carlsson Kanyama, A. et al. (2019) “We want to know where the line is”: comparing current planning for future sea-level rise with three core principles of robust decision support approaches. *Journal of Environmental Planning and Management*, 62(8), 1339-1358.
- Groves, D. et al. (2008) “Preparing for an Uncertain Future Climate in the Inland Empire: Identifying Robust Water Management Strategies”. Rand Corporation, Santa Monica.
- ITF (2016) *Adapting Transport to Climate Change and Extreme Weather: Implications for Infrastructure Owners and Network Managers*, ITF Research Reports, OECD Publishing, Paris. http://dx.doi.org/10.1787/9789282108079-en
- Jenelius, E. et al. (2006) Importance and exposure in road network vulnerability analysis. Transportation Research Part A 40(7), 537-560.
- Jenelius, E. and Mattsson, L.-G. (2021) Resilience of transport systems. I Roger Vickerman (Red.), *International Encyclopedia of Transportation*, pp. 258-267. Elsevier.
- Jones, R. N. et al. (2014) Foundations for Decision Making. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability*, edited by C. B. Field et al., 195–228. Cambridge: Cambridge University Press.
- Maier, H. R. et al. (2016) An uncertain future, deep uncertainty, scenarios, robustness and adaptation: How do they fit together? *Environmental Modelling & Software*, 81, 154-164.
- Walker, W. et al. (2003) Defining uncertainty: A conceptual basis for uncertainty management in model-based decision support. *Integrated Assessment*, *4*(1), 5-17.
- Wikman-Svahn, P. (2016) Principer för robusta beslut inför osäkra klimatförändringar. KTH Report TRITA-IM 205:02, ISNN 1402-7615.
- Wilby, R. L. and Dessai, S. (2010) Robust adaptation to climate change. *Weather*, 65(7), 176–180.