Coping with Uncertainties About Climate Change in Infrastructure Planning – An Adaptive Policymaking Approach

FINAL REPORT

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RAAD voor Verkeer en Waterstaat

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Preface

This report has been prepared in response to a request by the Board of the Netherlands Ministry of Transport and Water. This board was asked to investigate the issue of uncertainty surrounding infrastructure planning and development in the Netherlands in view of climate change.

The Board of the Netherlands Ministry of Transport and Water approached ECORYS Netherlands to prepare a report on current approaches for assessing and analysing uncertainty in policy analysis and to focus on adaptive approaches for policy analysis and policy making as a way for dealing with uncertainty.

Given the limited time available for preparing this report, it cannot provide a comprehensive overview of the literature on assessing and analysing uncertainty. Instead, we have chosen to focus on an approach, adaptive policy making, that has been developed by the authors as a way for both policy analysis and policy making.

We expect this approach will be of interest to policy makers involved with issues that are characterised by deep uncertainty.

Dr. Adnan Rahman
Managing Partner, ECORYS Transport

Executive summary

1 Introduction

Uncertainty is present in almost all decisions that we make in our daily lives. However, most of the time, the uncertainty is too small, or the consequences so insignificant that it does not require substantial consideration. We deal with uncertainty in our daily lives by using heuristics learned over time.[1] Sometimes, however, the magnitude of uncertainty and its potential consequences can be so large that heuristics can no longer be used to make decisions in such situations, and neither can we simply ignore uncertainty and act as if it does not exist.

Policymakers are regularly confronted with having to make choices in situations characterised by very high levels of uncertainty where the choices they make have potentially large consequences for society. The design and planning of infrastructure is one such area. Infrastructure for transport, energy generation, and water provision are essential for our daily lives, and disruptions in these infrastructures can have large consequences for society.

A good example of the effects of uncertainty on policy is the issue of climate change, and this is the central issue being considered by this report. The uncertainty as to whether climate change is taking place has now largely been removed.[2] There is, however, considerable uncertainty about:

- The extent of climate change (how quickly it is taking place),
- What this means for specific areas and regions (the effects of climate change are potentially larger for countries such as Bangladesh and the Netherlands than for countries like Mongolia), and
- What should be done to mitigate climate change and its adverse consequences.

The recent European Commission (EC) Green Paper on adaptation to climate change highlighted the potentially very large consequences of climate change (see box).

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[1] Kahneman, D., Slovic, P., & Tversky, A. (1982) Judgement Under Uncertainty: Heuristics and Biases

[2] Stern (2007) The Economics of Climate Change: The Stern Review, Cambridge, Cambridge University Press

Potential effects of climate change[3]

- In regions where precipitation will decrease or where dry summers will become more frequent, water flow for cooling of thermal and nuclear power plants and for hydropower production will reduce. The cooling capacity of water will also decrease because of the general warming of water and discharge thresholds may be crossed.
- River flow regimes will be altered due to changed precipitation patterns and in mountain areas due to reduced ice and snow cover. Silting of dams for hydropower may accelerate due to increased risks of erosion.
- Demand for heating will drop but the risk of power disruptions will raise as summer heat pushes up demand for air-conditioning resulting in an increased demand for electricity.
- Increased risk for storms and floods may threaten energy infrastructure.
- Major transport infrastructure with long lifetimes such as motorways, railways, waterways, airports, ports and railway stations, its functioning and related means of transport are weather and climate sensitive and therefore affected by a changing climate. For example:
    - Sea-level rise will reduce the sheltering effect of breakwaters and quays wall.
    - Risks for damage and disruption due to storms and floods but also due to heat waves, fires and landslides are generally expected to increase.

What is interesting about the EC Green Paper on adaptation is that it not only raises the issue of climate change as a problem because of its potentially large adverse impacts, but it justifies the strategy for dealing with climate change, adaptation, by linking it to uncertainty and the costs of actions to hedge against these uncertainties (see box "When to adapt?").

1.1 The problem of uncertainty about climate change in infrastructure planning

Most serious analysts agree that climate change is happening; scarcely a day goes by without a news report pointing some new piece of evidence pointing out the seriousness of climate change. There are, however, four key sources of uncertainty that pose problems for policymakers:

1. The magnitude of climate change is open to question; there are a whole range of future scenarios that describe very different increases in average temperatures. Even the Intergovernmental Panel on Climate Change, the premier international body charged with making forecasts about temperature increases resulting from climate change, has prepared a set of scenarios that differ in how much temperatures will increase.
2. There are questions about the speed of climate change; is climate change a slow process that will continue at the same rate as it has in the past, or will the rate of climate change increase? The key issues here whether we have enough time to

[3] European Commission (2007) Adapting to Climate Change in Europe – Options for EU action, {SEC(2007) 849}

postpone taking decisions for some more years, or must we start acting immediately?

3. While global temperature increases are reasonably reliable, the local and regional effects of these temperature increases are much less reliable. Thus, while we are reasonably sure that temperatures will increase by 1 to 2 degrees globally, we are much less certain about what these increases will mean for different parts of the world, and for different countries in even the same parts of the world.
4. Finally, there is also little consensus about how to react to global warming. This lack of consensus stems in part from the lack of knowledge about the costs and benefits of different alternatives for protecting ourselves from the adverse consequences of climate change.

These four issues raise the key question of how best to react in the face of these uncertainties and unknowns? Different responses are possible. To start there is the position that it is best for us to wait and see what happens, in the event that action is required; we can act quickly. A diametrically opposite perspective is to take action immediately without waiting to see what happens. These two opposing perspectives highlight the key problem, namely; meeting longer term objectives requires taking action now, while the decisions that are taken now have implications for the future. Thus, policymakers are confronted with having to ponder how best to trade-off the costs associated with short-term decisions against the long-term benefits. To complicate matters, these decisions have to be made in the face of significant uncertainty.

In this paper, we will argue that commonly used approaches for making policy are inadequate for dealing with climate change uncertainties in infrastructure planning, and we propose an alternative approach for policymaking, the adaptive policymaking approach.

When to adapt?[4]

Early action will bring clear economic benefits by anticipating potential damages and minimizing threats to ecosystems, human health, economic development, property and infrastructure. Furthermore competitive advantages could be gained for European companies that are leading in adaptation strategies and technologies. Sufficient knowledge on time dimensions of impacts is important when setting priorities. The exact level of temperature increase is uncertain and will also depend on global mitigation action taken over the next few decades. This is particularly the case for the longer time frames for which uncertainties are larger.

If there is no early policy response, the EU and its Member States may be forced into reactive un-planned adaptation, often abruptly as a response to increasingly frequent crises and disasters, which will prove much more costly and also threaten Europe's social and economic systems and its security. For impacts where we have enough confidence in the forecasts, adaptation must therefore start now.

How should Europeans adapt?

EU private sector, businesses, industry and services' sectors, as well as individual citizens will be confronted with the consequences of climate change and can play an important role in adaptation measures. Concrete action could range very widely, covering e.g.:

- Soft, relatively inexpensive measures, e.g. water conservation, changes in crop rotations, sowing dates and use of drought tolerant crops, public planning, and raising awareness.
- Costly defence and relocation measures, e.g. increasing the height of dykes, relocating ports, industry and entire cities and villages from low-lying coastal areas and flood plains, and building new power plants because of failing hydropower stations.

The European Commission Green Paper provides compelling arguments (and evidence) for treating uncertainty seriously in considering climate change and making policy, and underlines the potentially severe consequences of not doing so.

In the remainder of this chapter we outline the relevance of climate change for infrastructure planning, the uncertainties involved in the discussion on climate change, and why it is important to properly consider these uncertainties in policy making.

1.2 The relevance of climate change for infrastructure planning

A recent U.S study considered the following impacts of climate change to be relevant for transportation:[5]

- Increases in very hot days and heat waves
- Increases in Arctic temperatures

[4] Ibid.

[5] National Research Council (U.S.) - Committee on Climate Change and U.S. Transportation.(2008) *Potential impacts of climate change on U.S. transportation*, Transportation Research Board (TRB) Special Report 290, TRB, Washington D.C

- Rising sea levels
- Increases in intense precipitation events
- Increases in hurricane intensity

The recent Delta Commission report identified the following impacts of climate change as being relevant for the Netherlands:[6]

- Rising sea levels
- Growing shortage of sand
- Increases in wind and storm intensities
- Increase in the volume of water flowing through the Rhine and the Maas rivers
- Higher temperatures leading to sweet water shortages

The above impacts of climate change are very real and will pose problems for planners in the future (see box "Why climate change matters"). In the two above mentioned reports, the authors note and underline the uncertainties surrounding the magnitude of these impacts, as well as uncertainties in how to guard against the adverse effects of these developments.

Climate change has potential impacts for almost all the infrastructure (and almost everything else, see box "Australia's settlements and infrastructure – impacts of climate change) that underpins our way of life, including the infrastructure for:

- Transport
- Coastal defences
- Inland waterways
- Drinking water supplies
- Electricity generation and distribution
- Off-shore drilling platforms
- ICT
- Pipelines

Recently, the Dutch Ministry of Transport and Water asked the relevant Government institute (Knowledge Institute for Mobility, KIM) to prepare a report on the effects of climate change for transport and traffic infrastructure and what its implications for adaptation.[7] The primary question that this report is intended to address is whether there are policy measures in place to protect the Netherlands from the adverse effects of climate change, and how adaptation should be put into practice. It is worth reviewing this report and its conclusions as it is an official document that has provided inputs into the debate on how to react to the threat(s) posed by climate change. This report and its conclusions are reviewed below.

The basis for most policy discussions about how to react to climate change are based on four scenarios prepared by the Royal Dutch Metrological Institute (KNMI). These four scenarios describe a future that is moderate (G-), slightly more extreme (G+), warm (W-)

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[6] Delatcommissie (2008) Samen werken met water

[7] KIM (2008) Effecten van klimaat verandering op verkeer en vevoer

and very warm (W+). Table 1.1 gives the forecast average temperature increases, the temperature on the 10% of hottest and coldest days of the year, precipitation, the frequency of "wet days," mean and median precipitation and the precipitation on the 1% of the wettest days. These estimates are provided for the summer and winter months. What is clear from this table is that if the forecasts are accurate, the Netherlands is becoming warmer and drier, while at the same time the precipitation on the 1% of the wettest days is increasing. The comparison with the period 1975-2000 with 2050 confirms this.

Table 1.1 - Changes in temperature and precipitation in KNMI scenarios for 2050[8]

Variabele	G–	G+	W–	W+
Zomer				
Gemiddelde temperatuur (°C)	0.9	1.4	1.7	2.8
Temperatuur op 10% warmste dagen (°C)	1.0	1.8	2.0	3.6
Temperatuur op 10% koudste dagen (°C)	0.9	1.1	1.8	2.2
Gemiddelde neerslag (%)	2.8	−9.5	5.5	−19.0
Frequentie van natte dagen (%)	−1.6	−9.6	−3.3	−19.3
Gemiddelde neerslag op natte dagen (%)	4.6	0.1	9.1	0.3
Mediaan neerslag op natte dagen (%)	−2.5	−6.2	−5.1	−12.4
Neerslag op 1% natste dagen (%)	12.4	6.2	24.8	12.3
Winter				
Gemiddelde temperatuur (°C)	0.9	1.1	1.8	2.3
Temperatuur op 10% warmste dagen (°C)	0.8	1.0	1.7	1.9
Temperatuur op 10% koudste dagen (°C)	1.0	1.4	2.0	2.8
Gemiddelde neerslag (%)	3.6	7.0	7.3	14.2
Frequentie van natte dagen (%)	0.1	0.9	0.2	1.9
Gemiddelde neerslag op natte dagen (%)	3.6	6.0	7.1	12.1
Mediaan neerslag op natte dagen (%)	3.4	7.3	6.8	14.7
Neerslag op 1% natste dagen (%)	4.3	5.6	8.6	11.2

The report also examines the possible effects of these changes for transport and traffic infrastructure. We direct the reader to the complete report for a more detail on the effects and possible measures to adapt to these effects (KIM 2008), a summary is provided in Table 1.4. However, it is worth examining some of the conclusions of this report in more detail.

The KIM report gives a prominent position to another study carried out by an engineering consultancy (DHV, 2007) to investigate the role of the *Rijkswaterstaat* in building and maintaining road infrastructure. This study concluded the following:

> The implementation test foresees no big problems. A reactive (but not ad hoc) policy can be adopted. In such a case, the maintenance will be carried out when

8 KNMI (2006) in KIM (2008)

> and where necessary and will be intensified on an as needed basis leading to higher maintenance costs. A proactive policy can also be followed. In this case, the design criteria for construction of roads will have to be modified, and this will result in climate change having a smaller effect on maintenance costs. However, at this time, it is not known with any degree of certainty whether a reactive or proactive policy is more cost efficient. More knowledge is needed about the precise effects and possible solutions. …
>
> According to this study *(the DHV Study)* it is easy to imagine that the weather conditions will gradually change over a long period of time. Given this long time period, it will be possible to consider on a case by case basis whether a reactive or proactive policy is more desirable. Because of the relatively short life span of infrastructure (compared to the speed of climate change), there are enough possibilities for modification (of the infrastructure).[9]

The fact that the *Rijkswaterstaat* commissioned a study to investigate the potential impacts of climate change on its role and functioning is commendable. However, the suggestion that because climate change takes place slowly there will be enough time to adapt and modify the infrastructure, is disturbing. This suggestions is disturbing for two reasons. First, the assumption that the rate of future climate change will be the same as that today or what it was in the past is not based on any evidence, it is an assumption. And second, by making the suggestion, the authors of the report cultivate the impression that there is no reason for urgency, everything is under control.

Making assumptions in the making of policy is inevitable. However, there are good assumptions and there are bad assumptions. We will say more on this later. Here, it is sufficient to say, that if the DHV report is used as the basis for determining the construction and maintenance policy for transport and traffic infrastructure, the costs of the assumption (about the rate of climate change) turning out to be wrong could be very high. What we would also like to point out is that the focus of the DHV report is what can be called "tactical" issues. These issues are operational issues (to be fair *Rijkswaterstaat* is an organization with carrying out operational tasks). What is, however, worth considering, even for *Rijkswaterstaat*, are the strategic implications of climate change. For example, if two 10,000 years storms were to take place in a space of two years, what would be the role and response of *Rijkswaterstaat* in the restoration of affected infrastructure?

[9] Text translated from KIM (2008) pp. 17

Why climate change matters:[10]

First, it is not just a problem for the future. Recent changes, such as global warming and resulting sea level rises, reflect the effects of GHG emissions that were released into the atmosphere over the past century. What appears to be new is the greater certainty of scientists that human activity is already warming the climate and that the rate of change is likely to be greater than at any time in modern history (IPCC 2007b).

Second, climate change will not necessarily occur gradually. Climate scientists expect that higher temperatures will be amplified by normal variability in climate, leading to new extremes far outside current experience [e.g., the heat wave in Europe in 2003 (Stott et al. 2004) and the near record heat of 2006 in the United States (Hoerling et al. 2007)]. Higher temperatures are also likely to trigger surprises, such as more rapid than expected melting of Arctic sea ice and rising sea levels.

Third, although transportation professionals typically plan 20 to 30 years into the future, many decisions taken today, particularly about the location of infrastructure, help shape development patterns and markets that endure far beyond these planning horizons. Similarly, decisions about land use, zoning, and development often create demand for long lived transportation infrastructure investments. Thus, it is important for transportation decision makers to consider potential impacts of climate change now in making these investment choices because those impacts will affect how well the infrastructure adapts to climate change.

Fourth, professionals in many fields—among them finance, building (where protecting against earthquakes, wildfires, or wind risk is a concern), nuclear power, and water resources (in the design of dams and canals)— are continually making decisions in the face of uncertain information about risks and outcomes. In fact, the highway and bridge engineering community, through the auspices of the American Association of State Highway and Transportation Officials, has developed design guidelines and Potential Imp 28 acts of Climate Change on U.S. Transportation standards for earthquake resistance on the basis of probabilistic seismic hazard assessments that take many uncertainties into account. Similarly, addressing climate change requires more quantitative assessments, such as the development of probabilistic climate change scenarios at the level of geographic and modal specificity needed by transportation planners and engineers, which can be incorporated into planning forecasts and engineering design guidelines and standards.

Finally, transportation professionals already consider weather- and climate-related factors in designing and operating the transportation infrastructure. For example, many transportation networks and facilities are designed with adequate drainage and pumping capacity to handle a 100-year storm. Materials and maintenance cycles are geared to assumptions about temperature and precipitation levels. Evacuation plans and routes have been identified in hurricane- and other storm-prone locations on the basis of current elevations and assumptions about storm surges and wave action. But what if the 100-year storm were to become the 50-or 30-year storm, or design thresholds were frequently to be exceeded, or evacuation routes themselves were to become vulnerable? Such changes could necessitate different

[10] National Research Council (U.S.) - Committee on Climate Change and U.S. Transportation.(2008) *Potential impacts of climate change on U.S. transportation*, Transportation Research Board (TRB) Special Report 290, TRB, Washington D.C.

design criteria, asset management policies, maintenance cycles, and operating tragedies. Recent severe weather events—such as the Mississippi River floods of 1993, Category 3 or greater hurricanes (e.g., Ivan, Katrina, Rita), the California wildfires of 2003—provide ample opportunities for transportation professionals to observe the vulnerabilities of the infrastructure to shocks to the system that could become more commonplace in the future. They also illustrate the dilemma facing transportation decision makers of whether to rebuild, rebuild differently, or relocate critical transportation infrastructure.

1.3 Uncertainties in the science of climate change

The science of climate change is based on observation and computer simulations. Observations about the climate form the basis of climate change simulation. In 2001, The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) concluded with 95% confidence that global average surface temperatures have increased by 0.6^0C to $\pm 0.2^0$C (this is the 95% confidence interval) in the last 100 years. This statement is based on observation and measurement of temperatures over the last 100 years. The only uncertainty here is the measurement uncertainty and this is represented in the 95% confidence interval. This uncertainty is there because of gaps in the data, and the assumptions that are made in order to fill in these data gaps.

A much larger uncertainty in the climate change science is the uncertainty about the causes of this temperature increase. Here simulation models play a large and important role in what we know about the potential causes of climate change. Simulation models of the climate system model the main elements of this system, the interactions between these elements, and link these to human activities. While our understanding of the elements of the climate system and their interactions is quite well developed, it is still not sufficiently far advanced to reduce uncertainty to manageable levels.[11]

Finally, another large source of uncertainty is in trying to simulate climate change and its effects at a level of aggregation that is lower than the global climate. The reason for this uncertainty is that global climate change simulation models impose a grid on the entire globe. Thus, the results of these models are valid for the globe as a whole. Crudely put, the average results are roughly right for the entire globe. However, translating these results to a local or regional level poses major problems. The problem is that given our current knowledge, we cannot say with any degree of certainty whether a particular region falls in the range above or below the global average, and even if can answer this question, how much above or below the global average?

Thus, while almost everyone agrees that climate change is occurring, it remains very difficult to forecast with certainty how much the climate is changing, the speed of change, or the specific location of these changes. In short, in considering the effects of climate change for a particular region or country, we would be unwise to simply take the margin of uncertainty as presented by the IPCC.

[11] See Petersen, A. C., (2006) "Simulating Nature, A philosophical investigation of computer simulation uncertainties and their roel in climate science and policy advice" for an elaborate discussion of the uncertainties in the climate system

1.4 Consequences of uncertainties in climate change for infrastructure planning

There are two very good reasons why climate change and uncertainty matter, namely:

1. The costs of being surprised can be enormous. Although we know for certain that climate is changing, and these changes have clear implications for policy, our understanding about how global climate change will translate into regional and local effects and changes is still limited. Thus, we cannot assume with a great deal of certainty that the local and regional effects of climate change are accurate. The second source of surprise is the rate of climate change and the effects of accelerated climate change. Most planners and policymakers implicitly assume that climate change will continue at the same rate in the future as it has in the past. Based on this assumption, the argument is often made that there is enough time to take remedial action and put in place protective measures. This assumption, however, if wrong, can have disastrous consequences
2. The costs of delaying measures to safeguard against climate change is exponentially higher than the costs of taking action now.

In this section, we review two reports, the Stern Report and a report of the Dutch Institute for Environment and Public Health, that clearly point out why we need to properly consider uncertainty in infrastructure planning and in the making of decisions. The first example is from a recent study that estimated what it would cost the EU economies to deal with climate change with and without adaptation. The second example is the recent report of the Delta Commission that investigated the alternatives (and their costs) for protecting the Netherlands from sea level rises caused by climate change.

Estimates provide by the Stern review of climate change suggest that a 3-4°C global average temperature rise would result in additional costs - of adapting infrastructure and buildings – that could be as high as 1-10% of the total costs invested in construction in OECD countries; or $15-150 billion each year (0.05–0.5% of GDP).[12] If temperatures rise by 5-6°C, the costs of adaptation measures are likely to rise sharply, and their relative effectiveness diminishes. As shown in Figure 4, the costs of damage caused by sea-level rise without adaptation can be up to four times higher than the costs with additional flood defences. With no action, damage costs increase steeply from 2020s until the 2080s.[13]

As was pointed out earlier, no serious observer can dispute the evidence on climate change. There is, however, much debate and uncertainty about what climate change means, and what can be done about it. Figure 1.1 vividly shows that the magnitude of uncertainty associated with climate change and the costs of dealing with this uncertainty. An important conclusion that can be drawn from this figure is that if we postpone the solutions, it will cost us more to deal with the problem of climate change.

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12 http://www.hm-treasury.gov.uk/media/4/3/Executive_Summary.pdf

13 Ibid.

In the Netherlands, the Government institute for public health and environment (RIVM) estimated the costs of damage resulting from flooding of the dike rings in the Netherlands at €190 billion.[14] For a 24-60 cm sea level rise, the damage estimate in 2040 is somewhere between €400 – 800 billion. For a 150 cm sea level rise, the damage estimate in 2100 increases to €3700 billion.

The message that we draw from these examples is that the uncertainty in sea level rises (and the further out we go in time the more uncertain these estimates are) are not simply a matter of scientific debate, but it has a cost associated with it.

The second example that we would like to use comes from the report of the Delta Commission. The Delta commission estimated the costs of raising the level of protection offered by the Dutch coastal defences. Table 1.1 provides the annual investments, in billions of Euros, necessary to implement the recommendations of two versions of the Delta Program for improving the level of protection offered by the Dutch coastal defences.

[14] Aerts, J. B., Kolen, H. v.d. Most, Kok, S. v.'tKlooster, Satijn, B., & Leusink, A. (2007 Waterveiligheid en klimaatbestendigheid in breder perspectief.

Figure 1.1 - Estimates of damage with and without adaptation[15]

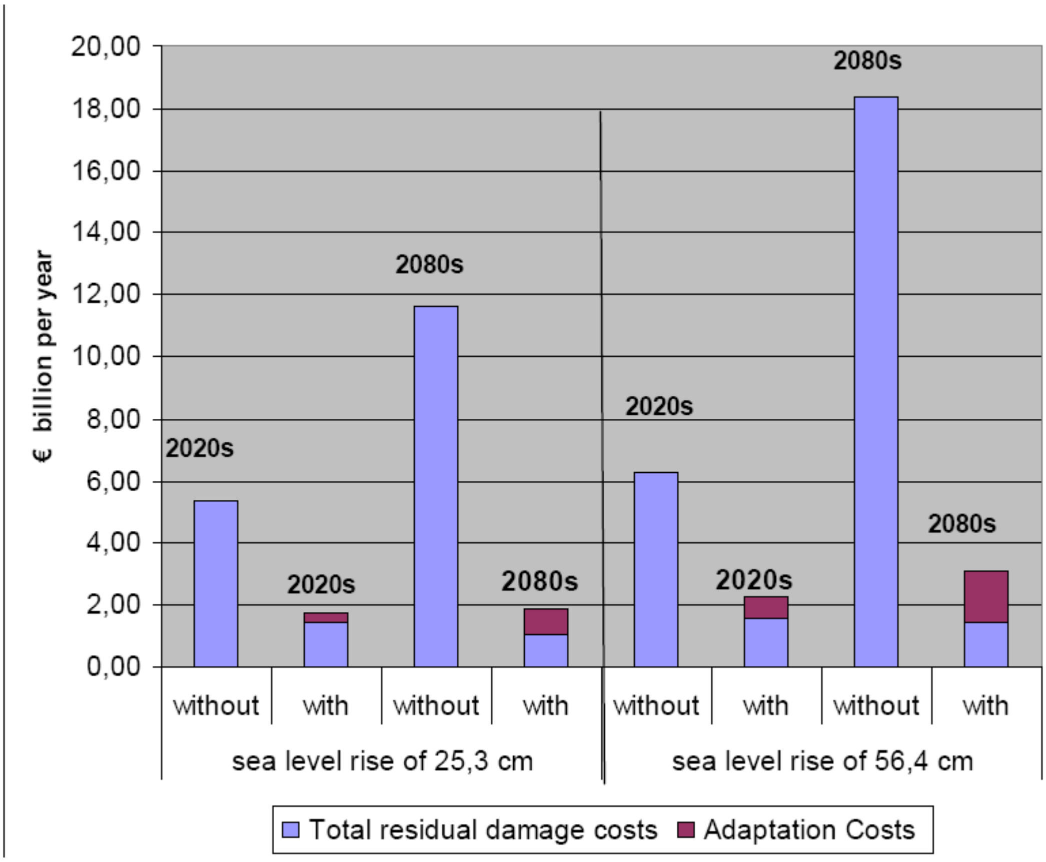


Table 1.2 - Estimates of the annual investments needed for improving Dutch coastal defences (billion Euros)[16]

	Period		Average
	2010 – 2050	**2050 – 2100**	**2010 – 2050**
Delta program	1.2 – 1.6	0.9 – 1.5	1.0 – 1.5
Delta program – expanded version	1.3 – 1.9	1.2 – 1.8	1.2 – 1.8

The ranges in the cells of Table 1.2 provide the estimates of needed investments under two scenarios. The upper end of this range represents conventional scientific thinking on the upper limit of sea level rise along the Dutch coast and the necessary investments to improve protection levels. What this tables also points to is the uncertainty surrounding climate change and the uncertainty in the estimates of the necessary investments to adapt to climate change.

While experts and scientists can disagree about the exact numbers that form the basis of the estimates in the above two examples, they can hardly avoid concluding that the

15 IPCC SRES scenario A2; costs by 2100 in 1995 €. Results from EC JRC PESETA study.

16 Deltacommissie (2008)

level of uncertainty surrounding climate change is large, as are the range of costs estimates for dealing with this uncertainty. Thus, regardless of how we look at it, ignoring uncertainty is not an option.

Table 1.3 - Consequences of KNMI scenarios for the climate in 2050[17]

	Uitgangswaarde 1975-2005	G-	G+	W-	W+
		scenario 2050			
Warme dagen	80	97	100	115	100
Zomerse dagen	24	30	34	39	47
Tropische dagen	4	7	9	10	14
IJsdagen	10	6	5	3	2
Vorstdagen	61	45	43	33	29
		20	15	35	25
Zomerneerslag		toename	afname	toename	afname
Winterneerslag		toename	toename	toename	toename
Windsnelheid		lichte toename		lichte toename	
Zeespiegelstijging (cm)		15-25		20-35	

[17] KIM (2008)

Table 1.4 - Effects and possible adaptation measures to address climate change[18]

Effecten	Adaptatie maatregelen
Infrastructuur aanleg, beheer en onderhoud	
spoorvorming (smeltend asfalt) bovenbouw wegen	verbeterde aanleg of vaker herstel (onderzoek)
wegen onder water door intensieve regenval	aanpassen ontwerpcriteria (maatgevende bui)
spoorstaafbreuken spoorwegen	verruimen dilataties (onderzoek)
uitval elektrische systemen (spoor)wegen	verbeteren, terugvalsysteem of vaker herstel
klemmende brugopeningen en sluizen	verruimen dilataties (onderzoek)
verweking onderbouw (spoor)wegen en luchthavens	verbeterde aanleg of vaker herstel (onderzoek)
inklinking onderbouw (spoor)wegen en luchthavens	verbeterde aanleg of vaker herstel (onderzoek)
overstroming binnenwateren	dijkverhoging of compartimentering, vluchtwegen
overstroming kust	dijkverhoging of compartimentering, vluchtwegen
kans op overstroming kades Rotterdam	inzicht ontbreekt (onderzoek nodig)
Afwikkeling verkeer en vervoer	
toename vaarbeperkingen binnenvaart	aanpassing binnenschepen, beperkte substitutie
afname beschikbaarheid en capaciteit wegen	kortdurend: geen, langdurig: omleiden
afname beschikbaarheid en capaciteit spoorwegen	kortdurend: geen, langdurig: omleiden
afname beschikbaarheid en capaciteit luchthavens	kortdurend: geen, langdurig: omleiden
toename belang weeralarmering	verder ontwikkelen, verbeteren en afstemmen
toename herstelwerkzaamheden	anticiperen op volume en tijdigheid
toename gebruik hulpmiddelen en hulpdiensten	toerusten op intensiever gebruik
toename belang evacuatie en noodplannen	eisen aan weginfrastructuur ontwikkelen
optreden congestie	wisselend effect, doorgaan huidig filebeleid
toename verkeersonveiligheid	geen substantieel effect, doorgaan huidig beleid
geluidsproductie	beperkt effect, doorgaan huidig beleid
uitstoot en vorming fotochemische smog	wisselend effect, doorgaan huidig beleid

[18] KIM (2008)

Australia's Settlements and Infrastructure - Impacts of Climate Change – Australian Department of Climate Change

Increases in temperature

- o Increase in peak demand for electricity in summer. However, peak demand for winter heating is likely to decrease.
- o Extreme temperatures are likely to have impacts on the production and transmission of energy. Higher temperatures are likely to affect the transmission efficiency of powerlines. Higher water temperatures (combined with reduced water availability) will result in decreased cooling capacity for thermo-electric power generation.
- o Extreme temperature events (heat waves) could cause disruptions to transport - through damage to transport infrastructure (e.g. road pavement and rails).
- o Increased maintenance costs of transport infrastructure as materials need to be replaced more often and/or with more resilient ones.
- o Decrease in the longevity of exterior materials of buildings and infrastructure, leading to increased maintenance and replacement costs.
- o Increased cost of cooling buildings and/or retrofitting to increase energy efficiency of buildings.
- o Extreme temperatures, especially heat waves, will have both direct and indirect effects on the health of vulnerable members of society (the elderly, the sick, the young and the poor).
- o Increased incidence of vector-borne and food-borne diseases. Increases in temperatures (combined with alterations in rainfall) are likely to result in geographical shifts in the incidence of tropical diseases, such as malaria, Ross River and Murray Valley encephalitis and dengue, into areas where they do not currently occur.
- o Increased the risk of bushfire.
- o Drier conditions associated with higher temperatures (combined with decreased rainfall) will result in more frequent dust storms.
- o Higher temperatures (and decreased rainfall) will make large water reservoirs more susceptible to toxic algal blooms.

Rainfall

- o Changes in annual rainfall patterns
- o Changes in the availability and quality of water supply. Settlements in areas where rainfall decreases (combined with higher temperatures) will experience decreases in supply.
- o Decreases in rainfall (combined with higher temperatures) is likely to reduce water quality through increased risk of algal blooms in water storage dams.
- o Decreases in rainfall and increased periods of drought, especially in inland settlements, will increase disruption to socio-economic infrastructure and human wellbeing.
- o Decreases in rainfall (combined with higher temperatures) is likely to increase the cost of maintenance of public green spaces, parks and playing fields in settlements.

Changes in intense rainfall events

- o Increases in rainfall may exceed the coping capacity of current stormwater and wastewater systems, leading to flooding and associated damage to infrastructure and property.
- o More intense rainfall events could result in flooding of sewerage systems and may cause contamination of water supply.
- o Heavy rainfall events and flooding could result in higher concentrations of accumulated

pollutants being flushed into streams, lakes and the ocean from settlements.

- More intense rainfall may increase damage to infrastructure and buildings in areas vulnerable to landslides and severe erosion events.

Altered frequency of extreme events

- Increased incidences of disruptions to key services, such as electricity supply and transport.
- Increased damage to physical and socio-economic infrastructure and human wellbeing.
- Insurance costs for extreme event damage are likely to increase.
- Higher accident rates, particularly on roads but also in the maritime shipping and aviation sectors.
- Increased risk of post-event disease outbreaks and other health-related impacts.
- Increased incidences of outbreaks of water-borne diseases, such as cryptosporidiosis and Giardiosis (from extreme rainfall).

Sea level rise

- Increased chance of damage to coastal buildings, infrastructure and recreational facilities through storm surges and flooding.
- Increased risk of high salinity in some coastal areas resulting in reduced productivity of land, as well as damage buildings and infrastructure.
- Increased risk of salination of surface and groundwater sources in coastal areas.

2 Current approaches for dealing with uncertainty in infrastructure planning

Someone said that the only thing we know with certainty is that there is uncertainty. Yet, a casual review of the scientific and policy literature will reveal that uncertainty is given scant attention. There are probably several reasons why this is so, but we do not review these reasons here. In this chapter, we first review the current decision making and analysis process for planning large infrastructure projects in the Netherlands and then review the methods that can be used to analyse uncertainty and deal with it in decision making.

2.1 Current process for planning infrastructure investments in the Netherlands

The current process for infrastructure planning has three phases:

1. Exploratory phase
2. Plan-study phase
3. Project preparation phase

Exploratory phase: The exploratory phase is an essential but informal part of the process. The activities in this phase are intended to determine the problem and whether it is important enough to be placed on the political agenda, whether the project that is being proposed is useful in addressing the problem, whether it poses risks to the environment, and whether it is financially feasible.

In theory, the exploratory phase should provide a complete picture of the problem, as well as insights into ALL possible solutions to deal with the problem. In practice, however, what is often seen is that the exploratory phase includes mostly engineering solutions to problems. For example, if there is traffic congestion on a national highway, typically the solutions include only possibilities for increasing the capacity of the existing highway, or new sections of highway. It does not include, for example, a consideration of alternative measures such as pricing, teleworking, etc., to relieve congestion on the highway.

Plan-study phase: The outputs and conclusions of the exploratory phase form the inputs and starting point for the plan-study phase. In this part of the process, the project alternatives for dealing with a problem are explored in more detail. Several “alignments” of the proposed alternatives are analysed to estimate the costs and benefit of each alternative. The output from this phase is a detailed design and administrative document for each of the project alternatives. This document outlines the exact physical location of the infrastructure, the proposed design, estimates the costs and benefits, and the environmental impacts.

Project preparation phase: In this phase, the technical and administrative elements of promising alternatives are elaborated upon in additional detail.

There are several aspects of this process that are worth noting. First, the exploratory phase where a policy problem is analysed and possible solutions explored is weak. There are no formal requirements in this phase as to consideration of alternatives, the sorts of costs and benefits to be considered, or any mention of how uncertainty should be considered in the analysis. Yet, this phase sets the stage for all subsequent activities and determines what sorts of solutions are considered and which are not.

A second point worth noting is that this process is biased against the consideration of non-infrastructure solutions to problems; the very process is initiated by pointing out bottlenecks on existing infrastructure. What this means is that not ALL possible solutions are considered and compared at the start of a project.

Third, in practice this process is a very long drawn out process. Experience shows that the full process can take well over decade from start to finish. Yet in this time, there are no formal mechanisms for revisiting and revising the information during earlier phases of the process. In fact, the process as it stands now is constructed in such a way that it discourages doing so. Given the length of time that elapses between the start and finish of this process, a lot can change in the intervening period to affect the problem and alternatives under consideration.

Finally, we note that the methods that are used for assessing the alternatives are inadequate for dealing with uncertainty. The formal requirement of the plan-study phase is an Environmental Effect Report (EIA). The primary method used to support the preparation of this report is Cost-Benefit Analysis (CBA). A CBA is woefully inadequate for dealing with uncertainty, and it gives little idea about the risks involved in a given alternative.

The results of applying this process to infrastructure planning have not been very good. Although little systematic ex-post evaluation has been carried out, newspaper reports, parliamentary debates, and some research [e.g., Flyvbjerg, B., "Policy and Planning for Large-Infrastructure Projects: Problems, Causes, Cures," *Environment and Planning B: Planning and Design*, vol. 34, 2007, pp. 578-597.] suggest that projects are often too late, cost too much, or do not deliver the promised benefits. Clearly, a more flexible process that explicitly considers uncertainty would be useful for planning infrastructure investments.

2.2 Approaches for dealing with uncertainty

Before delving into the various approaches used to deal with uncertainty, it is useful to provide a working definition of what we mean by uncertainty. When we use the term uncertainty, we use it to mean the lack of complete information on a phenomenon.

In the face of uncertainty, policy makers can deal with uncertainty using one or more of the following approaches:

1. Predict and act
2. Scenario analysis
3. Decision trees and influence diagrams
4. Real option analysis
5. Robustness and resilience methods
6. Assumption based planning

2.2.1 Predict-and-act

In this approach, policymakers make policy choices based on the available knowledge and information. Based on the assumption that sufficient knowledge and information about a policy problem is available, policymakers typically base their policy choices on a forecast of the future. These forecasts of the future are inevitably based on what has happened in the past. The usual approach for handling uncertainty in the predict-and-act approach is by means of providing a so-called confidence interval around the forecast of the future. This confidence interval typically provides a range within which we can be certain with a given level of confidence (typically 95%) that the future will lie.

In this approach, the implicit assumption underlying every forecast is that the future will continue to look significantly like the past; the future world will be structurally more or less the same as the current world – perhaps more populated, richer, dirtier – but, essentially the same. Unfortunately, there is no particular reason as to why the future should look like the past. By assuming it does, we do not solve the uncertainty problem, we merely sweep it under the rug, often with serious consequences.

Two examples – the Minitel case in France and the case of the Channel tunnel - make clear the potential consequences of assuming that the future will continue to look like the past. [19] The telephone company of France was a pioneer in the use of on-line interactive telecommunications. It committed itself, on the basis of the most careful analyses, to the development of the Minitel system. But, it failed to build in the capability to change as the world changed – to expand to more advanced platforms using improved technologies for the system. This resulted in a network that is now virtually obsolete in the Internet environment, and that cannot practically be adapted to the new technical realities. It is a dinosaur less than 20 years after its initiation.

[19] De Neufville, Richard, "Dynamic Strategic Planning for Technology Policy", International Journal of Technology Management, Vol. 19, Nos. 3/4/5, pp. 225-245, 2000.

In the example of the Channel tunnel, the developers of the tunnel ignored alternatives to the tunnel. The competition from low cost air carriers and price reactions of ferries were not taken into account in planning for the Channel tunnel project, which resulted in a significant overestimation of the tunnel's revenues and market position, with devastating consequences for the project.

The approach within this 'predict and act' paradigm start with building a model of the system of interest (e.g. transport system) in order to estimate the (often intended) outcomes of alternative policies, assuming some *(often trend-based)* future world. Next, the outcomes for different policies are valued using some form of cost-benefit analysis or multi-criteria analysis, in order to end up with a best policy. Hence, this approach resembles a driver who is driving his vehicle by looking in his rear-view mirror.

2.2.2 Scenario analysis

When faced with a level of uncertainty in which the predict-and-act approach visibly fails, policy analysts usually opt for scenario analysis, or 'what-if' policy analysis. This approach has worked fairly well in the past when change was more gradual and predictable, there was less global competition, and the consequences of being wrong were smaller. The core of this approach is that the future can be predicted well enough to identify policies that will produce favorable outcomes in one or more specific plausible future worlds. The future worlds are called scenarios. Policy analysts use best-estimate models (based on the most up-to-date scientific knowledge) to examine the consequences that would follow from the implementation of each of several possible policies in each scenario. The 'best' policy is the one that produces the most favorable outcomes across the scenarios. (Such a policy is called a robust policy.)

The benefits from using scenarios in policy analysis are threefold. First, it helps us to deal with situations in which there are many sources of uncertainty. Second, it allow us to examine the "what ifs" related to scenario uncertainties. It suggest ways in which the system could change in the future and allow us to examine the implications of these changes. Finally, scenarios provide a way to explore the implications of scenario uncertainty for policymaking (prepare for the future) by identifying possible future problems and identifying robust policies for dealing with the problems.

From an analytic perspective, however, the scenario approach has several problems. The first problem is deciding which assumptions to include in the scenarios. Typically, these assumptions are decided upon by experts (collectively and individually). However, in the face of uncertainty, no one is in a position to make this judgement. A second problem is that we have little idea about whether the range of futures provided by the scenarios covers ALL, 95% or some other percentage of the possible futures. Thus, even if we choose a policy that performs well in our scenarios, we have no idea whether this policy will perform well in the future or not. We can only say that the policy will perform well in the future if the future turns out to resemble one of the futures we have included in our scenarios. A third problem with this approach has to do with the large range in the performance estimates generated by the scenarios. If the uncertainty included in this range is large, policymakers often tend to fall back on the do-nothing approach with the following sort of reasoning, we do not have sufficient information to make a decision at this time. This is probably the worst possible outcome – when the level of uncertainty is high, and the potential consequences are large, it is imperative that policymakers act rather than wait.

The limitations of the scenario approach are illustrated using the example of Amsterdam airport Schiphol. In 1995, a number of major decisions regarding the future of Schiphol Airport were made. The main objective was to create room for Schiphol to become a mainport, while improving the quality of living in the area surrounding the airport. In order to come to a decision, forecasts were created based on three scenarios. During the development of the decision, it became clear that only one of the three scenarios would enable both objectives to be achieved. The final decision was based exclusively on the traffic demand forecasts derived from this scenario and involved the following measures:[20]

- Schiphol would be allowed to grow into a small hub airport, with KLM as its hub carrier that should serve roughly 40 to 45 million passengers in 2015
- A fifth runway would be built
- Until 2003, the expected year the fifth runway would open, the noise situation should not get worse than the situation in 1990, which implies a maximum of around 15,000 houses in the high noise contour (the so called "stand still" principle)
- After 2003, the maximum number of houses in the high noise contour would be lowered to 10,000 houses
- An insulation program for houses would be implemented within the high noise contour
- Investigate the development of Lelystad airport to relieve Schiphol
- A high speed rail link from the Netherlands to Belgium and France and from the Netherlands to Germany would be developed that stopped at Schiphol, in order to reduce the number of short-haul flights from Schiphol.

As it turned out, the limits of the noise regulations were reached in 1999, leading to a temporary shut down of the airport, and the passenger limit was reached in 2005. The two-year costly process that aimed at developing a plan adequate for 20 years turned out to have a lifetime of only ten years. How did this happen? The model used to create the demand forecast was based upon a relationship between GDP and traffic demand that represented past experience quite well. However, due to a number of trend breaks – unanticipated changes in the world of civil aviation – that happened after the forecasts had been made, this relationship no longer produced good predications, resulting in forecasts significantly lower then the traffic demand actually experienced. The unexpected high rate of growth of air traffic demand was due to (i) an unanticipated rapid growth of the hub

[20] Dutch Parliament, Tweede Kamer 1998-1999. *Groeicijfers Schiphol; Rapport*. 26265 nr. 2. obtained from http://www.rekenkamer.nl/9282000/d/tk26265_2.pdf on July 30 2007.

network of KLM, leading to an increase in transfer passengers; (ii) an alliance between KLM and Northwest Airlines, which fed passengers from both airlines through Schiphol; and (iii) The European Union's liberalization of the air transport industry, which increased competition among air carriers, lowering air fares, and paving the way for low cost carriers.

Hence, in these and other cases, decisions must be taken when there is not only a lack of certainty about the future situation or about the outcomes from policy changes, but also when some of the possible changes themselves remain unknown. Here, decisionmaking is faced with the continual prospect of possible surprise. It is in this grey area between the known and what is not known that uncertainty ought to affect the approach to decisionmaking. The ultimate goal of decisionmaking in the face of uncertainty should be to reduce the undesired impacts from surprises, rather than hoping or expecting to eliminate them.[21]

Hence, traditional approaches have serious shortcomings in handling uncertainties regarding long-term transport policymaking in an appropriate way. The challenge for enlightened policymaking is to develop other, innovative approaches to handle these uncertainties. Instead of focusing on the identification of all feasible long-term transport solutions and development paths, which would be a waste of resources, an approach is needed that adapts to the future course of events and fully exploits knowledge that becomes available as time proceeds.

2.2.3 Decision trees and influence diagrams

"Decision analysis" refers to a technique to aid decision-making under uncertainty. While the name "decision analysis" generally refers to the overall field of using analytic techniques in support of decisionmaking, decision analysis is also more commonly thought of as that set of techniques that generally uses decision trees or influence diagrams in assisting decisionmaking.

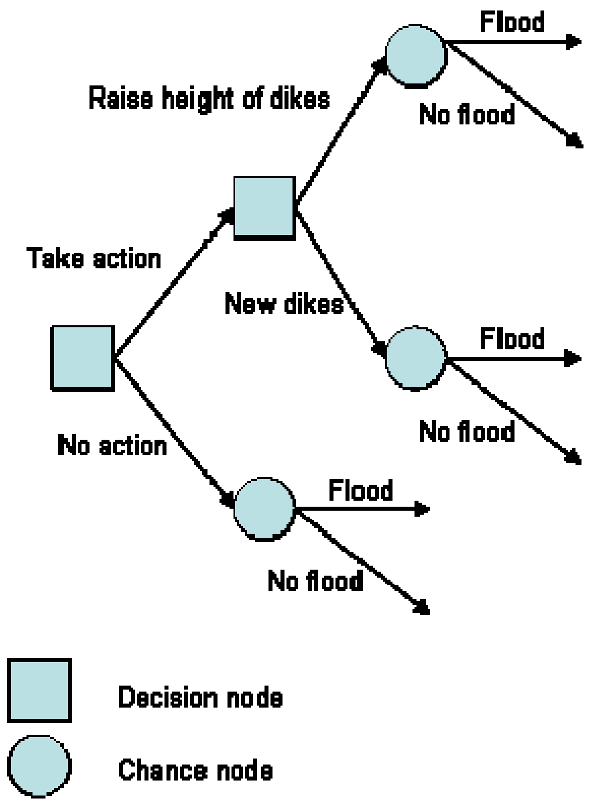
A decision tree is a structure composed of nodes and links connecting nodes. For a given decision, the tree starts with the basic options (for taking action or not) as branches from the first node. Consider an example where the choice is whether or not to take action to protect the population from floods, and if so, how? The first choice facing a decision maker is whether to take any action at all, or to do nothing. For the branch of the tree representing a decision to take action, the next node will represent the available choices for increasing protection levels choice faced by the decision make (if s/he takes action) are the options for improving the protection level. Suppose there are two possibilities for doing this; raising the height of the existing dikes, or building some new dikes. These two options then become the two branches of this node. Each of these options rests on uncertainties and subordinate decisions. Consider the branch of the tree Take action –Raise

[21] Dewar, J.A. (2002). *Assumption-Based Planning: A Tool for Reducing Avoidable Surprises*, Cambridge University Press, Cambridge, UK.

height of dikes. There are two possibilities at this stage, either there is a flood, or there is no flood.

Assume the probability of a flood is .01 (we know this is very large, but this is for illustrative purposes). Then the possibility that there is no flood is .99. Consider the branch Take action –Raise height of dikes - Flood. Continuing with the above example, we now we put the losses that would result from a flood. In the case of no flood, the losses are zero (or simply the cost of the take action branch). The "value" of each branch of the decision tree is the probability multiplied by the losses. A comparison of the values of each branch of the decision tree leads to identifying the best course of action for a decision maker.

Figure 2.1 - An illustrative example of a decision tree



For problems that are less quantitative, influence diagrams are used in a similar fashion. Influence diagrams represent the main structural features of a situation and the important influences that exist among those features. Unlike the arrows in a decision tree, the arrows that represent the influences of one box on another in an influence diagram can point in both directions. Influence diagrams are thus an abstraction of decision trees, but otherwise work in much the same way for handling uncertainty.

Using decision trees to help guide decision makers in complex policy settings can be useful inn terms of the discipline that such techniques enforce in thinking about problems. The problem, however, with such techniques is that they still require models for estimating and assigning probabilities to chance events, benefits and costs. As pointed out earlier, even the best of models remain imperfect at best in predicting the future. Thus, decision analysis, while helpful, still does not adequately help us deal with the problem of uncertainty, especially in situations such as climate change, where our understanding of the underlying processes and phenomenon is still far from being complete.

2.2.4 Real options

Real options originated in the world of finance and can be helpful in bringing together quantitative and qualitative data and information together in a decision analysis. A real option when it is present allows decision makers to change their investment decisions as new information becomes available. Real options are different from financial options insofar that they are tangible and are irreversible investments.

Real option can be put into two broad categories; real options "on" systems and real options "in" systems. Real options on systems take external factors into consideration and regard the system itself as a black box.

The way real options work is by valuing the flexibility in a given system or policy. The real options approach begins with NPV computations and extends those calculations to consider the intertemporal opportunity costs associated with making an immediate irreversible capital investment or waiting. The value of a real option is estimated by estimating the Net Present Value (NPV) of the "flexible" option and subtracting the NPV calculated in the traditional way.

NPV calculations require making precise predictions of future cash flow profiles for a project over its entire duration. Real option calculations, while more complicated, allow for the exploration of various cash flow profiles in the future. This allows decisionmakers to look at the NPV of a project over a wide variety of future cash flow profiles.

A simple example illustrating the usefulness of real options is that of a parking garage: how large should a parking garage be if future demand is uncertain. If the capacity of the parking garage exceeds future demand for parking, it will mean unnecessary investment, if the capacity is less than future demand, it will mean lost revenues from parking fees. In this case, a real option would be to lay the foundation of a parking garage that is strong enough to support several additional floors, but to build additional floors as future demand becomes visible. The real option analysis in this case would help decide on how many floors to build to start out with, and at what point it would be sensible to add additional floors.

The real option approach to assessing uncertainty suffers from many of the same problems as the other approaches insofar that it requires knowing future cash flows, and it requires some idea about the probability of future events. However, on the positive side, this approach explicitly recognizes that the future is uncertain and allows decision makers to explore the implications of decisions in the face of this future uncertainty. Thus, the real option approach could be useful in combination with other approaches for assessing and managing uncertainty.

2.2.5 Robustness and resilience methods[22]

Human decisionmakers often approach the solution of a complex problem by developing a strategy that will be robust against uncertainties about the future. While these are generally *ad hoc*, subjective approaches to robust decisions, interest in more explicit approaches to identifying robust, as opposed to optimum, strategies has been growing over the last two decades. This interest has been fueled in part by increasing realization by decision makers that the world is less predictable and more surprising than they might have believed, by advances in the psychology of decision making which show the traditional expected utility framework is not the way skilled human decisionmakers often approach reasoning under uncertainty, and by the advance of new computer capabilities which has made possible new quantitative decision frameworks. The Robust Decisionmaking (RDM) approach developed at RAND is an example of this emerging field and demonstrates the distinctive features of seeking robustness rather than optimality in the face of uncertainty of the type that climate change threatens.

The RDM approach uses computers to create a large collection of plausible future scenarios, where each scenario represents one guess about how the world works and one choice among many alternative strategies people might adopt to influence outcomes. The approach then uses computer visualization and search techniques to extract information from this collection of scenarios that is useful in distinguishing among alternative decision options. The second case study below gives a detailed example of the approach.

Four key elements or principles govern the form and design of an RDM analysis:
1. Consider *ensembles* of large numbers of scenarios. Such ensembles should contain a set of plausible futures that is as diverse as possible in order to provide a challenge set against which to test alternative near-term policies. Scenario ensembles can represent a wide range of different types of information about the long-term future. They can also facilitate group

processes designed to elicit information and achieve buy-in to the analysis from stakeholders with very different values and expectations about the future.

[22] Dewar, J. & Wachs M., (2008) Transportation Planning, Cliamte Change, and Decisionmakinng under Uncertainty, RAND, Santa Monica

2. Seek *robust*, rather than optimal, strategies that do "well enough" across a broad range of plausible futures and alternative ways of ranking the desirability of alternative scenarios. Robustness provides a useful criterion for policy analysis because it reflects both the normative choice and is the criterion that many decisionmakers actually use when facing complex problems and deep uncertainty.

3. Employ *adaptive* strategies to achieve robustness. Adaptive strategies evolve over time in response to new information. Near-term adaptive strategies seek to influence the longterm future by shaping the options available to future decision-makers. That is, the near-term strategies are explicitly designed with the expectation that they will be revisited in the future as new information becomes available.

4. Use computer tools designed for *interactive exploration* of the multiplicity of plausible futures. Humans cannot track all the relevant details of the many scenarios. But working interactively with computers, they can discover and test hypotheses that prove to be true over a vast range of possibilities. Thus, computer-guided exploration of scenario and decision spaces can help humans, working individually or in groups, discover adaptive near-term strategies that are robust over large ensembles of plausible futures.

Robustness methods are an improvement on any method aimed at sensitivity analysis. Transportation planners do, in some cases, explore the sensitivity of plans to alternative values for variables such as demography and the performance of alternative travel modes. Because of the run times of transportation models, however, few go beyond using something like "low, medium, and high" values. Particularly with the nonlinearities inherent in transportation models and the uncertainties surrounding climate change, such rudimentary low-medium-high sensitivity analyses may hide important system responses at intermediate values. Robustness methods can explore automatically over a wider range of values and increases in the speed of computers and in running parallel computations will decrease the time required to run additional cases.

2.2.6 Assumption based planning

A study done in 1999[23] noted several instances in which large companies suffered significant downturns due to situations they could easily have foreseen had they done a better job of planning. Specifically, the study pointed out assumptions in each case that the companies made that failed, causing the downturn. In the cases noted, had the companies paid more attention to the assumptions they made in their planning, those downturns might have been avoided. That study went on to recommend a variety of techniques for ensuring that planners are aware of their

[23] *Proceeding in Daylight: Frontier Practices for Challenging Strategic Assumptions*, Corporate Strategy Board, Corporate Executive Board, Washington, DC, 1999. See also, http://www.executiveboard.com.

important assumptions and plan accordingly. Assumption-Based Planning (ABP), developed at RAND, was one of the techniques mentioned and serves as a good example of the techniques for paying attention to planning assumptions.

Assumption-Based Planning was developed in the 1980s as a tool for improving the robustness of plans. Its main purpose is to expose the important assumptions underlying a plan – particularly those assumptions that planners don't realize, or have forgotten, that they are making. Planning for the future requires making assumptions about what the future will be like. Some of those assumptions are pretty likely to come true; others are more vulnerable to uncontrollable and unforeseen events; still others may be quite unlikely. Some of the assumptions are likely to be very important to the success of the plan; others will be more peripheral. ABP is primarily a "post-planning" tool (recognizing that planning is an iterative process) that concentrates on the assumptions in an already-developed plan that are most important to the plan's success and that are most uncertain. Specifically, ABP works to decrease the risks that assumptions represent.

The driving force behind ABP is the view that it is important to confront, explicitly and honestly, the uncertainties facing an organization and its planners. There are five basic steps in Assumption-Based Planning. The first step is to identify the assumptions in the plan. This is the most crucial step in ABP and there are several methods for identifying as many of the assumptions as possible that underlie a given plan. Many of a plan's assumptions will be explicitly spelled out and easy to identify. The primary purpose of this step is to uncover assumptions that are implicit or have been 'forgotten' in the planning process.

The next step in ABP is to identify the assumptions upon which the success of the plan most heavily rests--the "load-bearing" assumptions--and the assumptions that are most vulnerable to being overturned by future events. Assumptions that are both load-bearing and vulnerable are the most likely to produce nasty surprises as the plan unfolds.

To deal with potential surprises, ABP produces three things in the final three steps: signposts, shaping actions, and hedging actions. *Signposts* are warning signs that can be used to monitor those assumptions that are most likely to produce surprises. Signposts are events or thresholds that, if detected, signify that a vulnerable assumption is broken or dangerously weak and that management or planning action is called for.

Shaping actions are intended to help shore up uncertain assumptions, and thus to control the future to the extent possible. Planners generally know how they would like an assumption to play out. Shaping actions are designed to help the assumption play out to the planners' liking.

Hedging actions better prepare for the possibility that an assumption will fail, despite efforts to shore it up. Hedging actions typically come from thinking through a plausible scenario in which an assumption collapses and asking what might be done now to prepare for that scenario.

A planner using Assumption-Based Planning cannot hope to identify all the possible ways in which a plan could fail, nor hope to prepare a plan for any eventuality. There is any number of events that could intervene to disrupt any plan. The primary aim of ABP is to ensure that a plan is cognizant of and responsive to major uncertainties inherent in the assumptions that underlie it. Many of the assumptions upon which the plan rests are voluntarily made by the planners. Those voluntarily made assumptions should be most explicitly recognized and dealt with. Surprises from the failure of those assumptions should be most avoidable.

Any transportation plan could use the kind of assumption scrubbing that techniques such as ABP offer. With respect to climate change, however, there is one area where it is crucial to scrub for underlying assumptions – in the models used in the transportation sector to do longrange planning. Those models have been used for years – sometimes for decades – and the assumptions that underlie them may be inappropriate in a climate-changed world. Particularly susceptible to inappropriate assumptions are likely to be land use models that have not taken into account limits on future land development that will arise because of climate change. Also susceptible are mode choice and traffic assignment models because particular facilities included in such models may be far more vulnerable to climate change than others. Testing the assumptions of these models would need to be done either with someone very familiar with them or following careful documentation of the models.

2.3 Shortcomings of traditional approaches for dealing with uncertainty in policy analysis

In discussing the shortcomings of the above approaches we distinguish between the first four approaches (predict and act, scenarios analysis, decision trees, and real option analysis) and the last two approaches (robustness and resilience methods, and assumption based planning).

The fundamental problem with the first four approaches is that:

- They assume that we know the structure of the system sufficiently well; i.e., the model of the system is complete
- In one form or the other, a model is used to forecast the future. Even assuming that the model is adequate, there is the implicit assumption that the future will look like the past. In the case of climate change in particular, this is a dangerous assumption.
- The treatment of uncertainty is not systematic or complete. Uncertainty is often ignored, or estimates of uncertainty are based on expert opinions.
- Essentially, this leads to underestimation of uncertainty and over confidence in our ability to anticipate the future.
- Finally, and this criticism is particularly directed at the predict-and-act and scenario analysis approaches. While these approaches attempt to deal with uncertainty (with varying degrees of success), they do not help decision makers in making decisions, they complicate decisions.

The last two approaches, Robustness and resilience methods and Assumption Based Planning, make a bigger effort at dealing with uncertainty. However, while they do a better job of understanding uncertainty, they do not embed the analysis in an institutional framework. Thus, while they are helpful in the analysis, they are less helpful in the actual making of policy.

Thus, we propose using an adaptive approach, since it acknowledges that the future cannot be known with any certainty, can use the traditional approaches as and when needed, and embeds analysis in an institutional framework.

3 Policy analysis and uncertainty

Policy analysis means different things to different people and encompasses a wide range of activities, methods, and approaches. Depending on the problem at hand and the objectives of the analysis, policy analysis can use quantitative modelling techniques, or qualitative techniques; policy analysts can act as researchers, sophisticated users of research, or political advisors. What is evident from the literature on policy analysis is that there is no one unique way to conduct a policy analysis, and there are a multiplicity of perspectives, approaches, roles, and methods for the conduct and practice of policy analysis. Given this diversity, for the purposes of this paper, it becomes important to clearly understand and define the activities relevant for the analytic treatment of uncertainty.

In this chapter we provide a framework for thinking about policy analysis, the policymaking process, uncertainty, and the ways in which policy analysis addresses this uncertainty.

3.1 The policy analysis process

We use a conceptual model developed by Mayer et al. [24] Mayer et al. characterise policy analysis as a set of six interacting activities (see Figure 2.1), namely:

1. Research and analyse
2. Design and recommend
3. Clarify values and arguments
4. Advise strategically
5. Democratise
6. Mediate

Research and Analyse

This perspective represents a cluster of activities that are aimed at generating knowledge and understanding about a particular issue/problem with a view to supporting policymakers in the making of policy.

Design and recommend

[24] Mayer, I., P. Bots & E. van Daalen (2004) Perspectives on policy analysis: a framework for understanding and design, In: *Journal of Technology, Policy and Management*, 4 (2) pp 169-191, ISSN 1468-4322.

Once a policy issue/problem is sufficiently well understood, i.e., there is enough data and information to support the making of policy, the analysis focuses on using the available knowledge to develop a new policy by comparing policy alternatives and making policy recommendations. Policy recommendations are typically made by comparing the effects of policy alternatives using multiple criteria.

Clarify values and arguments
Underlying every policy debate or discussion are implicit values, norms, and judgements. These implicit values, norms, and judgements come to the surface in normative and ethical disagreements about policy choices that the available knowledge, data, and information cannot adequately resolve. In such situations, policy analysis can help by analyzing the underlying belief systems of opposing sides in a policy debate.

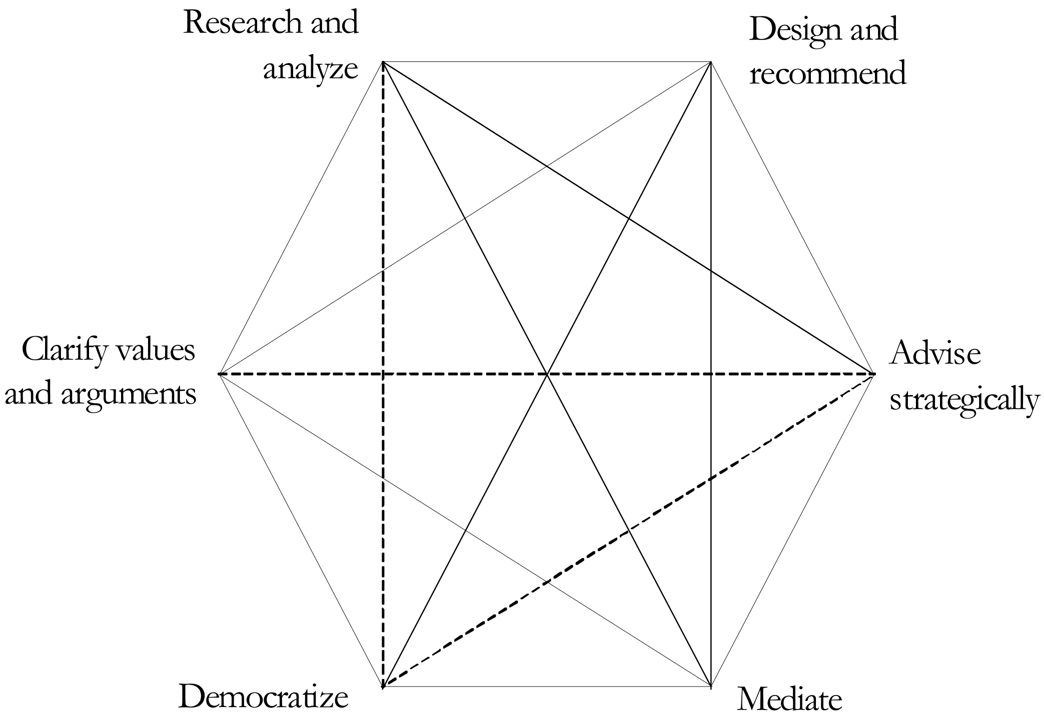
Advise Strategically
A policy analyst can advise a client on the most effective strategy for achieving certain goals not just based on the analysis, but also on a consideration of other factors, for example, the prevailing political sentiment, the reactions of those opposed to the policy, etc.

Democratise
Some have suggested that policy analysis should become 'a policy science for democracy by helping to promote equal access to, and influence on the policy process for all stakeholders.'[25]

Mediate
Sometimes resolving a policy debate requires mediation. Policy analysts can play a role as process designer or process supervisor – the policy analyst designs the rules and procedures for negotiating in a policymaking or decisionmaking process and manages the interaction and progress of that process. The activities in this cluster revolve around analyzing contextual factors (such as stakeholders, issues, dependencies, tradeoffs), and designing and facilitating meetings bringing together stakeholders and decisionmakers to consult and negotiate.

[25] DeLeon, P. (1988) *Advice and Consent: The Development of the Policy Sciences*, New York: Russell Sage Foundation; Lerner, D., H.D. Lasswell (eds.) (1951*) The Policy Sciences, Recent Developments in Scope and Methods*. Stanford California: Stanford University Press.

Figure 3.1 – A model of activities comprising policy analysis



For the purposes of this paper, we divide these six sets of activities into two groups -- analytic and political. The analytic group consists of two sets of activities: research and analyse, and design and recommend. The political group consists of the other four sets of activities. The reason for doing this is that we distinguish, and draw a line, between analysis and decisionmaking. Analysis is scientific and has no room for politics (this does not mean that analysis is 100% objective; rather, the biases and assumption should be stated up front). Decisionmaking can be based on and makes use of analysis (this is not necessarily the case), but is unavoidably political.

3.2 A framework for policy analysis

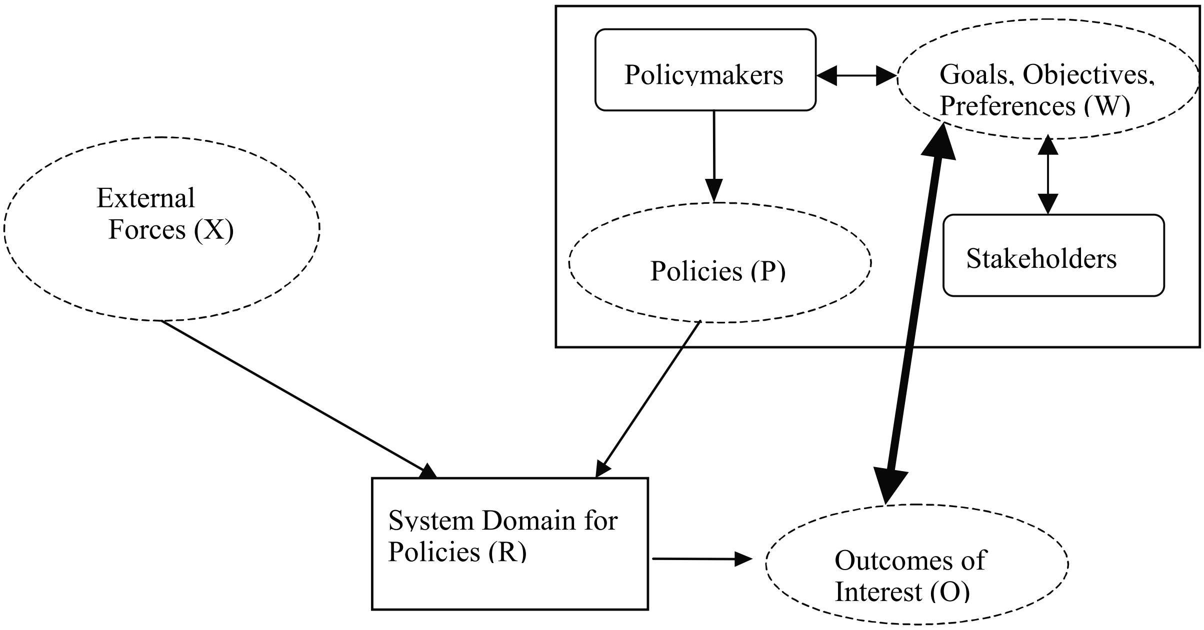
The search for good infrastructure policies can be supported by a structured process that takes an integrated view with respect to the various alternative policy options, their possible consequences for transport system performance, and how the various actors in the policymaking process value the consequences. Such a process (called 'policy analysis') has been described by Walker (2000)[26]. In essence, policy analysis views policymaking as making choices regarding a system in order to change the system outcomes in a desired way (see Figure 2.2).

[26] Walker W.E. (2000) Policy Analysis: A Systematic Approach to Supporting Policymaking in the Public Sector, *Journal of Multi-Criteria Decision Analysis*, 9(1-3): 11-27.

At the heart of this view is the *system* comprising the policy domain, e.g. the transport system, energy system, water system, etc. A system can be defined by distinguishing its physical components (e.g. passengers/cargo/information/water, vehicles/loading units, and infrastructural networks) and their mutual interrelationships (R). The results of these interactions (the system outputs) are called *outcomes of interest* (O) and refer to the system outcomes that are considered relevant criteria for the evaluation of policies. Well-known outcomes of interest for policymakers include throughput, reliability, safety/security, environmental stress, costs, etc. The *importance of the outcomes* refers to the (relative) weights (W) given to the outcomes by crucial stakeholders, including policymakers, reflecting their goals, objectives, and preferences. In case there is a gap between (some of) the outcomes of interest and the goals of the crucial stakeholders, *policies* (P) can be implemented (e.g. more efficient use of existing infrastructures, build new infrastructures) to influence the behaviour of the system in order to help to reduce the gap and achieve policy goals.

If policies were the only possible forces affecting the system we would have a 'closed loop' system, based upon which policymakers could fully control the system in order to reach their desired goals. However, in reality, there are also *external forces* (X) that influence the system. External forces refer to forces that are not controllable by the policymaker but may influence the system significantly (e.g. technological developments, demographic developments, economic developments). As such, both policies and external forces are developments outside the system that can affect the structure of the system and, hence, the outcomes of interest to policymakers and other stakeholders.

Figure 3.2 - The policy analysis framework



In general, a policy analysis includes the following steps[26]:

1. structuring the policy problem according to the policy analysis framework (see Figure 2.2)
2. building a model of the system relevant for policy analysis
3. carrying out computational experiments to estimate the outcomes of different policies
4. comparing the different outcomes of these policies.
5. choosing the best policy for implementation

The precise way these steps are specified and executed depends in part on the assumptions one has about the locations where uncertainty can manifest itself in the framework presented in and how these uncertainties are taken into account.

3.3 Uncertainty and policy analysis

In general, uncertainty is defined as *missing knowledge*; i.e., the absence of information. However, uncertainty is not simply the absence of knowledge. Funtowicz and Ravetz[27] describe uncertainty as a situation of inadequate information, which can be of three sorts: inexactness, unreliability, and border with ignorance. However, uncertainty can prevail in situations where a lot of information is available[28]. Furthermore, new information

[27] Funtowicz, S.O. and Ravetz, J.R.: *Uncertainty and Quality in Science for Policy*. Kluwer Academic Publishers, Dordrecht, 1990.

can either decrease or increase uncertainty. New knowledge on complex processes may reveal the presence of uncertainties that were previously unknown or were understated. In this way, more knowledge illuminates that our understanding is more limited or that the processes are more complex than thought before[29].

With respect to policymaking, uncertainty refers to the gap between available knowledge and the knowledge needed in order to develop and implement good policies. As such, in developing new policies, policymakers are initially confronted with uncertainty about outcomes and uncertainty about the relative importance of the outcomes. Evidently, this uncertainty in policymaking clearly involves subjectivity, since it is related to the satisfaction with existing knowledge, which is coloured by the underlying values and perspectives of policymakers. Formally, we will consider uncertainty to be "*any departure from the (unachievable) ideal of complete determinism*."[30] Or, in mathematical terms:

Let Y be some event. If Probability(Y) $\neq 1$, then the event Y is uncertain.

In terms of the policy analysis framework of , one can identify two primary locations of uncertainty regarding what policy to choose: (1) uncertainty about the outcomes, and (2) uncertainty about the relative importance placed on the outcomes by the participants in the policymaking process. These two locations of uncertainty are shown in Figure 1 and are discussed in more detail below.

Uncertainty about the outcomes can result from uncertainty about the future development of the *external forces* (e.g. how will climate change, how will future transport/water/energy demand develop, which technologies will become available) and/or uncertainty about *system responses* to these external forces and to the infrastructure policies implemented (e.g. to what extent will users/operators accept an infrastructure policy, how will infrastructure policies affect the outcomes of interest). Uncertainty about external forces relates to the missing knowledge about plausible alternative future developments in the environment of the system of interest, and can be further decomposed into: (1) uncertainty about the *relevant external inputs*), and (2) the possible *values of these relevant inputs*. Even if there were certainty about the external inputs to the system (that is, we knew how the external world would develop), there might still be uncertainty about how the system would respond to those external inputs (i.e., the appropriate way to model the resulting system). Uncertainty about the appropriate model might be due to *structural uncertainty* and/or *parametric uncertainty*. Structural uncertainty refers to the selection of the relevant system components and the identification of the relationships among these components (e.g., the functional relationship between climate change and sea level rise and/or weather

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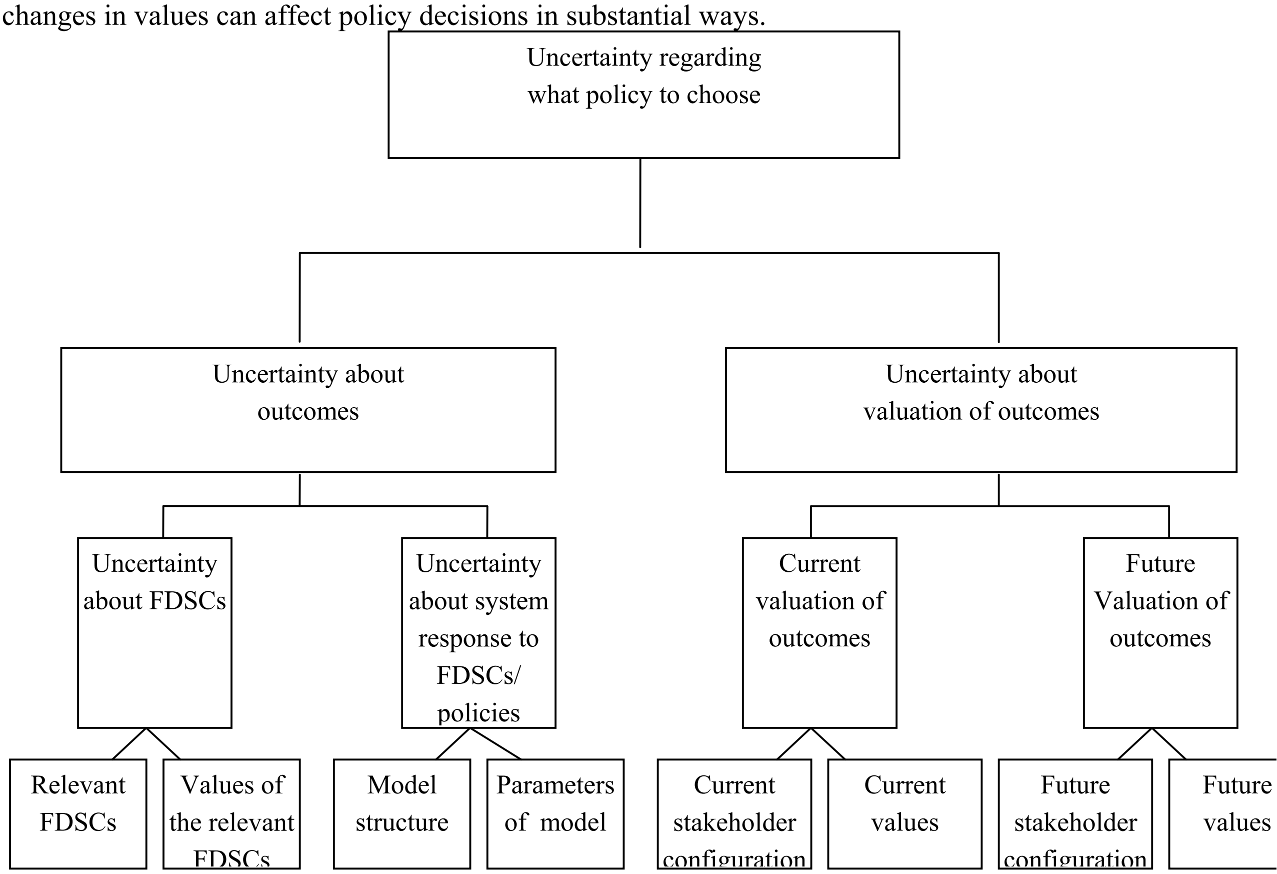
[28] Van Asselt, M.B.A. and Rotmans, J.: "Uncertainty in Integrated Assessment Modelling: from Positivism to Pluralism", Climate. Change, 54 (2002), pp. 75–105.
[29] Van der Sluis, J.P.: *Anchoring Amid Uncertainty: On the Management of Uncertainties in Risk Assessment of Anthropogenic Climate Change*, Ph.D. dissertation, University of Utrecht, Netherlands, 1997.
[30] Walker W.E. , P. Harremoes, J. Rotmans, J.P. van der Sluis, M.B.A. van Asselt, P. Janssen and M.P. Krayer Von Krauss (2003),"Defining Uncertainty: A Conceptual Basis for Uncertainty Management in Model-Based Decision Support", *Integrated Assessment*, 4(1), pp 5-17.

patterns). However, even if we were sure about the components and their relationships, there would still be uncertainty regarding the values of the parameters describing the relationships, i.e. *parameter* uncertainty.

The second location of uncertainty refers to the (relative) *importance given to the outcomes* by crucial stakeholders. One can distinguish uncertainty about the *current stakeholders' configuration and their current values* as well as the *future stakeholders' configuration and their future values.* Even if the people who are affected by a policy are clear, there might still be uncertainty about how each of these stakeholders currently value the results of the changes in the system. The uncertainty about current values is related to different perceptions, preferences, and choices the system's stakeholders currently have regarding outcomes. And, even if the outcomes are known and there is no uncertainty about the current stakeholders' configuration and their valuation of outcomes, in time, new stakeholders might emerge and the values of the current stakeholders may change over time in unpredictable ways, leading to different valuations of future outcomes than those made in the present. For instance the occurrence of a specific event (e.g. disaster), unexpected cost increases, or new technologies can lead to changes in values. These changes in values can affect policy decisions in substantial ways.



3.4 Deep Uncertainty: Climate Change and Infrastructure Planning

Infrastructure planning in the face of climate change is an example of a class of problems requiring decisionmaking under conditions of *deep uncertainty*—that is, where analysts do not know, or the parties to a decision cannot agree on, (1) the appropriate conceptual models that describe the relationships among the key driving forces that will shape the long-term future, (2) the probability distributions used to represent uncertainty about key variables and parameters in the mathematical representations of these conceptual models, and/or (3) how to value the relative desirability of the various outcomes[31]. In the case of infrastructure planning in the face of climate change, there is deep uncertainty with respect to most if not all of the boxes in the uncertainty hierarchy given above.

Decisionmaking under conditions of deep uncertainty require new analytic approaches and new types of policies. The considerations with respect to climate change and its implications discussed in Chapter 1, and the shortcomings of the traditional approaches for dealing with uncertainty discussed in Chapter 2 suggest that new approaches to decisionmaking under conditions of deep uncertainty are needed. Under deep uncertainty, decisionmakers need to seek robust strategies that work reasonably well over a wide range of plausible futures. However, instead of using scenarios to identify robust static policies, we believe that the best way to achieve robustness under conditions of deep uncertainty is by developing dynamic *adaptive* policies. Adaptive policies evolve over time in response to new information. Chapter 4 describes the framework for developing adaptive policies and presents two illustrative examples (one of which relates directly to the problem of sea-level rise resulting from climate change).

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[31] Lempert, R., S. Popper, S. Bankes, *Shaping the Next One Hundred Years*, RAND, MR-1626-RPC, 2003.

4 Adaptive Policymaking

4.1 Definition of the concept of adaptive policies

The concept of adaptive policies can be traced back to 1927, when John Dewey[32] proposed that 'policies be treated as experiments, with the aim of promoting continual learning and adaptation in response to experience over time'. But, such an approach has rarely been used since then. This approach allows implementation to begin prior to the resolution of all major uncertainties, with the policy being adapted over time based on new knowledge. It is an innovative way to proceed with implementation of long-term policies despite the uncertainties. The approach makes adaptation explicit at the outset of policy formulation. Thus, the inevitable policy changes become part of a larger, recognized process and are not forced to be made repeatedly on an ad-hoc basis. Adaptive policies combine actions that are time urgent with those that make important commitments to shape the future, preserve needed flexibility for the future, and protect the policy from failure. Under this approach, significant changes in the system would be based on a policy analytic effort that first identifies system goals, and then identifies policies designed to achieve those goals and ways of modifying those policies as conditions change. Within the adaptive policy framework, individual actors would carry out their activities as they would under normal policy conditions. But policymakers, through monitoring and mid-course corrections, would try to keep the system headed toward the original goals.

The concept of adaptation is easy to explain.[33] It is analogous to the approach used in guiding a ship through a long ocean voyage. The goal – the end point – is set at the beginning of the journey. It remains constant. But, along the way, unpredictable storms and other traffic may interfere with the original trajectory. So, the policy – the specific route – is changed along the way. It is understood before the ship leaves port that some changes are likely to take place – and contingency plans may have already been formulated for some of the unpredictable events. The important thing is that the ultimate goal remains unchanged, and the policy actions implemented over time remain directed toward that goal. An adaptive policy would include a systematic method for monitoring the environment, gathering information, implementing pieces of the policy over time, and adjusting and re-adjusting to new circumstances. The policies themselves would be designed to be incremental, adaptive, and conditional.

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[32] Dewey, J. (1927) *The Public and its Problems*, Holt and Company, New York.
[33] Walker, W.E. (2000) Uncertainty: the challenge for policy analysis in the 21st century, Inaugural Speech, TU Delft, Delft.

Guiding the ship of state in this adaptive way may be revolutionary in many policy areas. But, it is already an accepted approach in some. For example, the U.S. Federal Open Market Committee and the European Central Bank set inflation targets and then change interest rates as conditions in the economy change. It is also rapidly becoming a guiding principle – indeed, a requirement for survival –in the private sector.

The analysis and choice of an adaptive policy would require a new process for policymaking that explicitly takes into account the uncertainties and dynamics of the problem being addressed. Adaptive policymaking can be divided into two phases: a 'thinking phase' and an 'implementation phase.'[34] In the *thinking phase* the policy problem is formulated, the policy analysis is conducted, and the adaptive policy is specified, including the rules for its implementation. The *implementation phase* consists of the actual sequence of events and actions that represent the execution of the previously agreed upon adaptive policy. I will briefly present the process to you today as food for thought.

4.2 Steps in adaptive policymaking

A large literature review conducted at the International Institute for Sustainable Development found that the literature relating directly to the topic of adaptive policies is limited.[35] Only recently, Walker et al.[34] proposed a specific, stepwise approach for adaptive policymaking.

Figure 4.1 illustrates the adaptive policy process. In particular, the following steps summarize the process for creating and implementing an adaptive policy.

[34] Walker, W.E., Rahman, S.A., and Cave, J. (2001) "Adaptive policies, policy analysis, and policymaking", *European Journal of Operational Research*, 128(2), 282-289.
[35] IISD (International Institute for Sustainable Development) (2006) *Designing Policies in a World of Uncertainty, Change and Surprise - Adaptive Policy-Making for Agriculture and Water Resources in the Face of Climate Change – Phase I Research Report*, IISD, Winnipeg.

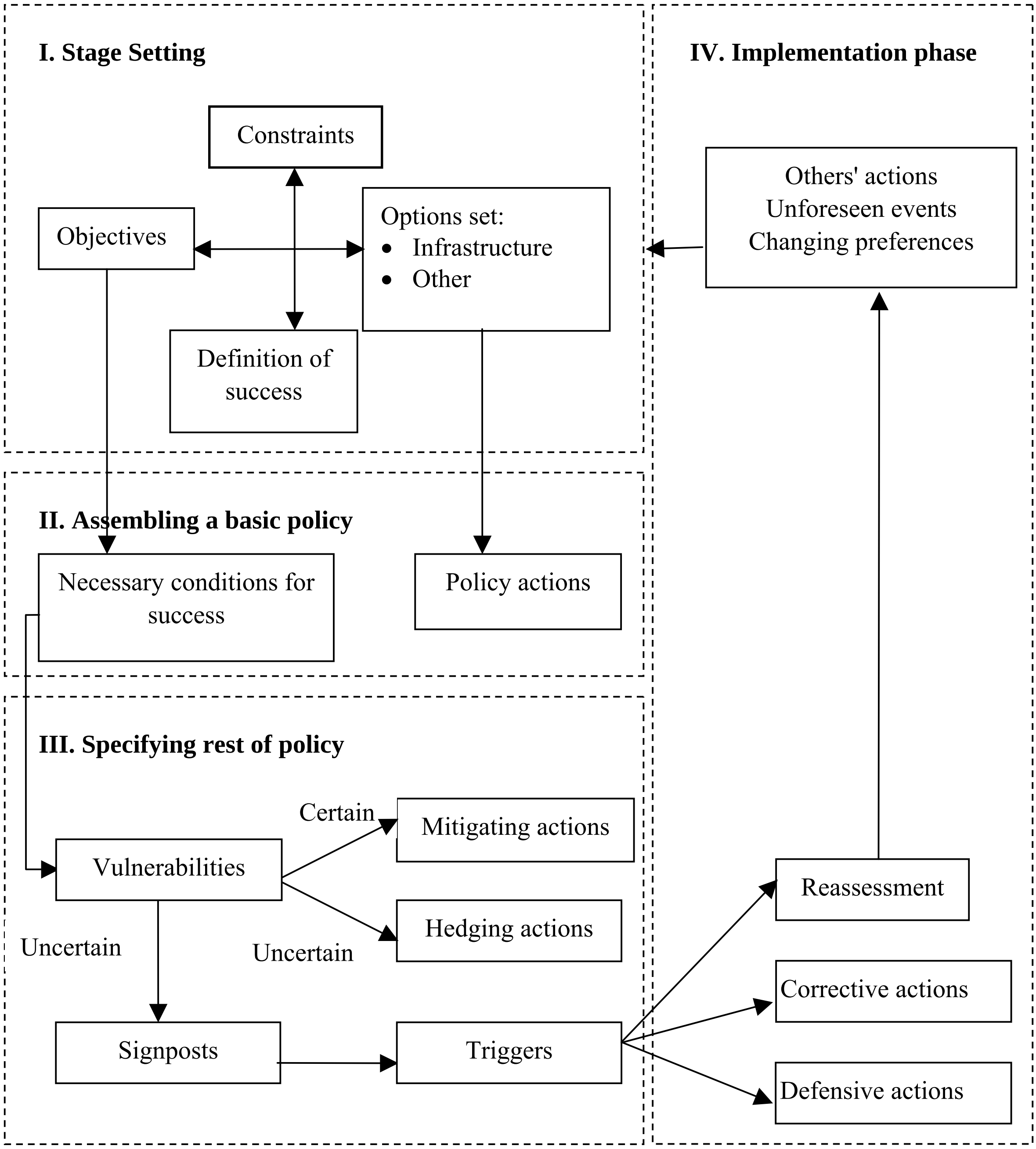

Figure 4.1: The adaptive policymaking process

Both the first and the second steps are basically the same steps as are used currently in policy formulation. The first step constitutes the *stage-setting* step in the policymaking process. This step involves the specification of objectives, constraints, and available policy options. This specification should lead to a definition of success, i.e. the specification of desirable outcomes. In the next step, a *basic policy* is assembled, consisting of the selected policy options and additional policy actions, together with an implementation plan. It involves (a) the specification of a promising policy and (b) the identification of the conditions needed for the basic policy to succeed. These conditions should support policymakers by providing an advance warning in case of failure of policy actions.

In the third step of the adaptive policymaking process, the *rest of the policy* is specified. These are the pieces that make the policy adaptive. This step is based on identifying in advance the vulnerabilities of the basic policy (the conditions or events that could make the policy fail), and specifying actions to be taken in anticipation or in response to them. This step involves (a) the identification of the vulnerabilities, (b) defining actions to be taken immediately or in the future, and (c) defining signposts that should be monitored in order to be sure that the underlying analyses remain valid, that implementation is proceeding well, and that any needed policy interventions are taken in a timely and effective manner. Vulnerabilities are possible developments that can reduce the performance of a policy to a point where the policy is no longer successful. Actions are defined related to the type of vulnerability and when the action should be taken. Both certain and uncertain vulnerabilities can be distinguished. Certain vulnerabilities can be anticipated by implementing mitigating actions – actions taken in advance to reduce the certain adverse effects of a policy. Uncertain vulnerabilities are handled in two ways. First, by implementing hedging actions – actions taken in advance to reduce or spread the risk of possible adverse effects of a policy. Second, by specifying possible future actions. For the latter vulnerabilities, signposts are defined and a monitoring system established to determine when actions are needed to guarantee the progress and success of the policy. In particular, critical values of signpost variables (triggers) are specified, beyond which actions should be implemented to ensure that a policy keeps moving the system in the right direction and at a proper speed. Note that apart from vulnerabilities to the basic policy, opportunities might also be considered in this step. Opportunities are external developments that improve the performance of a policy so that it is more successful than it would have been without these external developments. These opportunities should be monitored as well in order to take advantage of the developments and, for instance, expand the basic policy.

Scenarios are very useful for identifying vulnerabilities in the basic policy, and for identifying mitigating and hedging actions for dealing with them. We use van der Heijden's (1996, p.5)[36] definition of an "external scenario". He says "external scenarios . . . are created as internally consistent and challenging descriptions of possible futures. . . What happens in them is essentially outside our own control." The scenarios are used to address the ways that the basic policy could go wrong (i.e., not lead to success). Thus, they do not have to be as detailed as scenarios used for developing a new (robust) policy.

Scenarios are usually constructed in one of two directions: backward (backcasting) or forward (forecasting). Because we are concerned with end states – the failure of the basic policy – the best means for constructing an adaptive policymaking scenario is to use backcasting. The challenge then is to describe why the world unfolded the way it did, and what were the factors that made it unfold that way. The primary focus should be on the

[36] Van der Heijden, K. (1996) *Scenarios: The Art of Strategic Conversation*, New York: John Wiley & Sons.

“plot” – the story that connects the present with how the basic policy would fail, and what that failure would lead to. (The story will require some “driving forces” and some “logic” – i.e., why the forces behave the way they do.)

The primary challenge in constructing an adaptive policymaking scenario is to make it credible. Often, the most credible scenario of the future will be the one that is most like the present. However, in adaptive policymaking, since each scenario is built around a vulnerability of the basic policy, each scenario will differ from the present in an important way. So, none of the scenarios will look very much like the present. As a cautionary note, a very negative scenario is likely to be viewed as less credible than a merely negative one. Research[37] suggests that people tend to view very negative scenarios as implausible and reject them out of hand.

Once the above policy is agreed upon, the final step involves *implementation*. In this step, the actions to be taken immediately are implemented, a monitoring system is established, signpost information related to the triggers is collected, and policy actions are started, altered, stopped, or extended. After implementation of the initial mitigating and hedging actions, the adaptive policymaking process is suspended until a trigger event is reached. As long as the original policy objectives and constraints remain in place, the responses to a trigger event have a defensive or corrective character – that is, they are adjustments to the basic policy that preserve its benefits or meet outside challenges. Under some circumstances, neither defensive nor corrective actions might be sufficient. In that case, the entire policy might have to be reassessed and substantially changed or even abandoned. If so, however, the next policy deliberations would benefit from the previous experiences. The knowledge gathered in the initial adaptive policymaking process on outcomes, objectives, measures, preferences of stakeholders, etc., would be available and would accelerate the new policymaking process.

[37] Janis, I., and L. Mann (1977) *Decision Making*, New York: The Free Press.

4.3 An illustrative example of adaptive policymaking I: Maglev

High speed rail is becoming an increasingly important mode for passenger transport, since as road traffic is expected to get worse and airport delays are expected to continue to increase. However policymaking on rail projects faces many uncertainties including future demand, technnological developments, investment expenditures, and benefit per user.[38] As such an adaptive policy might be a way to start implementation right away, despite these uncertainties.

Step 1: Specification of objectives, constraints, and available policy options
Within the EU, the challenge for rail transport policies involves, among others, the development of an effective high-speed passenger network.[39] Objectives for such high-speed network can be manifold. In literature and policy documents, the most often mentioned objectives are related to consumer benefits (reducing travel times, increasing consumer surplus), regional economic benefits (stimulating the regions where the high-speed railway stations are located), and macroeconomic benefits (stimulating the economy of the country, or at least a significant part of the country) (Bruinsma et al., forthcoming). With respect to policy alternatives, the dominant focus has been based on implementing 'conventional' high-speed train options, both on new and upgraded tracks, traveling at speeds of about 250-300 km/h. A relatively new option in this category is the implementation of 'magnetically levitated (Maglev) systems. Maglev systems involve magnetically-levitated trains that glide above their guideways and are guided and propelled by electromagnetic forces. Since the Maglev train floats, i.e. there is no friction, compared to conventional high-speed trains it is capable of higher speeds (up to 500 km/h), faster acceleration and deceleration, lower energy consumption (at the same speed), and produces less noise. Maglev trains and tracks require much less maintenance compared to conventional 'wheel on steel' railways. Constraints on Maglev policies are first of all financial: Maglev trains are expensive. Constraints might also relate to the impact on nature. Entirely new infrastructure is required, and EU regulations forbid crossing certain vulnerable areas. Network integration of Maglev with conventional rail is not easy to accomplish. And, even if it is legally allowed to build a line in a specific area, resistance from the public or action groups might put constraints on the route. A definition of success might include certain minimum travel time and convenience gains for travelers, a minimum mode shift from air to train, and/or an improvement of a regional or national economy.

Step 2: Basic policy and its conditions for success

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[38] Van Wee B. (2007) Large infrastructure projects: a review of the quality of demand forecasts and cost estimations, *Environment and Planning B*, Vol. 34: 611-625.
[39] CEC (Commission of the European Communities) (2001) *European Transport Policy for 2020: Time to Decide*', COM(2001)370, Office for Official Publications of the European Communities, Luxembourg.

In order to be competitive with air transport, the basic policy might be the construction of a Maglev line between two major economic centers, separated by long distances (e.g. 400-700 km)[40]. The basic policy should leave options open for possible future additions, such as connecting additional railway stations. Conditions for success of the policy include user acceptance, financial support, cooperation of relevant actors (e.g., particular local and regional authorities, action groups and rail transport companies that might offer services on the line) and interconnectivity with other transport networks,

Step 3: Vulnerabilities of the basic policy and anticipatory actions

Table 4.1 presents some vulnerabilities[41] in relation to the basic conditions as well as possible responses to those vulnerabilities.

Table 4.1 - Dealing with vulnerabilities of the basic Maglev policy

Vulnerabilities	Mitigating/Hedging Actions	Possible Signposts/ Triggers/Actions
Certain: Basic support of relevant actors is required for Maglev construction	Mitigating Actions: • Prespecify agreements with construction companies, authorities, etc on prices, unforeseen problems, changes in project specifications; • Compensate for the expected disadvantages, e.g. provide environmental compensation, plan shuttle services to/from Maglev stations from unconnected important centers	
Certain: Interconnectivity with other transport networks	Mitigating Actions: • Provide good links to other networks, e.g. plan shuttle services to/from Maglev stations from unconnected important centers	
Uncertain: Revenue development	Hedging Actions: • Spread investment/	• Monitor travel demand together with a trigger for actions related, for instance, to the

[40] Nauman, R., Schach, R., and Jehle, P. (2006) An Entire Comparison of Maglev and High-Speed Railway Systems. *Proceedings of the 19th International Conference on Magnetically Levitated Systems and Linear Drives* (September 2006), TU Dresden, Dresden, 753 – 758.

[41] Flyvbjerg, B., Bruzelius, N., Rothengatter, W. (2003) *Megaprojects and Risk: an Anatomy of Ambition*, Cambridge University Press, Cambridge.

Vulnerabilities	Mitigating/Hedging Actions	Possible Signposts/ Triggers/Actions
	revenue risks among public and private parties • Educate travelers on the benefits of Maglev	number of travelers required to reach the intended revenues; in case the number of travelers is too low, implement corrective actions (e.g., lower prices, provide additional services, make competing air travel and/or competing rail lines less attractive)
Uncertain: Interaction of Maglev with regional development/land use around Maglev stations	Hedging Action: • Plan development/land use proactively around Maglev stations, i.e. prespecify agreements with regional authorities, e.g. to discuss urban extensions near potential Maglev stations;	
Uncertain: Technological failure	Hedging Action: • Invest heavily in safety systems	
Uncertain opportunity: Success of initial Maglev system		Monitor ridership and revenues together with a trigger related to, for instance, number of travelers and level of revenues; in case of more travelers and revenues than expected, extend the network and/or schedule more trains on the existing network

Step 4: Implementation

Finally, the basic policy is implemented, together with mitigating/hedging actions and signpost information begins to be collected. In case of a trigger event, some pre-defined action is undertaken. If, for instance, the number of travelers appears to be too low, some corrective action can be undertaken – e.g., giving some financial incentive for travelers to use the Maglev service or to make air travel and/or competing rail lines less attractive. After the full line between the two end stations is finished, extending the Maglev network might be an option, that partly depends on the success of the Maglev services under consideration. For instance, if the travel demand for Maglev appears higher then the demand needed for reaching the initial objectives, as stated in step 1, additional Maglev trains might be scheduled on the existing link and/or the Maglev network might be extended. For some trigger events, only a full reassessment of the basic policy might be sufficient. In case some of the key actors are not willing to participate anymore, e.g., if the returns on investment remain too low, the entire policy might come under serious pressure. However, the knowledge gathered in the initial adaptive policymaking process on outcomes, objectives, measures, preferences of stakeholders, etc., would already be available and would accelerate the new policymaking process (e.g., to help find new funding sources).

4.4 An illustrative example of adaptive policymaking II: Sea level rise

Climate change is expected to affect the entire low-lying part of the Netherlands and its coast. The issue is whether policies can be developed that make the Netherlands 'climate proof' in the long term. In this example we focus, for illustrative reasons, on one specific part of the Netherlands: the North Sea coast. The extent to which sea levels will rise in the future, and how quickly they will rise, is still deeply uncertain. As such, policies are needed that are flexible and adaptable, enabling learning to take place on the relationship between climate change and sea level rise. In this illustration, we assume that it has already been decided to carry out all of the backlog of maintenance on the existing sea dikes, in order to bring them up to the current safety norm (since this has nothing to do with sea level rise).

Step 1: Specification of objectives, constraints, and available policy options
The objective 'climate proof' has been specified as: "safe against flooding, while still remaining an attractive place to live, to reside and work, for recreation and investment."[42]. Policy options might include raising coastal protection to the recently proposed 'Veerman' norm (i.e., 10 times more safe than the current safety norm)[11] and relocating vulnerable people and goods to areas less vulnerable to flooding. The constraints on these policies are financial (increased coastal protection is expensive), acceptance of the implications of the increased coastal protection, timing (construction should reach the agreed new safety level before a flood happens), etc.

Step 2: Basic policy and its conditions for success
Assume that the basic policy is to start immediately to increase coastal protection to meet the recommended 'Veerman norm', and to begin a new in-depth study of the recommended 'Veerman norm', in order to further examine to what extent this norm does represent a proper balance between preventing casualties and social disruption on the one hand and avoiding damage to the economy, landscape, nature, culture, and reputation on the other hand[11]. In other to avoid confusion, we will label the proposed Veerman norm the 'intermediate norm' and the norm to be developed the 'final norm'.

Conditions for success of the basic policy would include:

1) Financial support for improving the coastal protection
   a) The ability to accumulate the money over time
   b) There is enough money accumulated
2) Sand to improve the coastal dikes
   a) There is enough sand
   b) There is enough transport (e.g. boats) available when needed to transport the sand

[42] Deltacommittee (2008) *Working with water: Advice to the Dutch Government.* (http://www.deltacommissie.com/)

3) Time to implement the policy
   a) The sea level does not rise too quickly
   b) There are no devastating storm surges before the policy is fully implemented
4) Decisionmaking on the final norm is fast enough

Step 3: Vulnerabilities of the basic policy and anticipatory actions
Table XX presents some of the main vulnerabilities of the basic policy specified in Step 2, as well as possible responses to those vulnerabilities. The first two vulnerabilities of the basic policy are independent of future climate change (and rise of sea level). In other words, whatever the future sea level may be (1) the way funding is a certain vulnerability, which requires mitigating actions, and (2) the amount of funding is an uncertain vulnerability, which requires a hedging action.

The next two vulnerabilities of the basic policy relate to uncertainties with respect to future sea level rise, in terms of the speed of the rise and the occurrence of storm surges that may cause serious flooding. Both of these aspects of the future world require hedging actions in the adaptive policy, since they could threaten the success of the basic policy. The final vulnerability relates to uncertainty about reaching consensus on the final norm. There is a hedging action to prepare for this situation. Note that reaching a consensus on the final norm will trigger actions to implement it in the coastal defenses; failure to reach consensus in time will trigger a defensive action, e.g. implement a national flood security law.

Step 4: Implementation
In the implementation phase, the basic policy and the mitigating/hedging actions are implemented. In addition, the monitoring system for the signposts is set up and information is collected. In case of a trigger event, some pre-defined action is undertaken. If, for instance, the sea level is rising faster then expected, some corrective action can be undertaken -- e.g., stationing empty oil tankers along the coast for interim flood protection. For some trigger events, however, a full reassessment of the basic policy might be required. If, for instance, a large flood occurs in an early stage, the entire policy might have to be reconsidered. However, the knowledge gathered in the initial adaptive policymaking process might support the new policymaking process, and e.g. construction plans can be cancelled, changed, or increased.

Table 4.2: Dealing with vulnerabilities of the basic sea level rise policy

Vulnerabilities	**Mitigating/Hedging Actions**	**Signposts/ Triggers/Actions**
1a – Certain: Currently, there is no way of accumulating coastal defense money over time	Mitigating Action: • Prepare an emergency law to make such savings over time possible (e.g., a 'Delta Fund')	
1b – Uncertain: The money might not be there when needed to meet the final norm	Hedging Action: • Once the 'Delta Fund' is in place, start saving according to the	Monitor developments with respect to decisionmaking on the final norm. In case the final norm changes the intermediate norm, undertake corrective action (i.e., increase or

Vulnerabilities	**Mitigating/Hedging Actions**	**Signposts/ Triggers/Actions**
	requirements of the final norm	decrease the rate of saving)
2a – Uncertain: There might not be enough sand available	Hedging Action: • Begin studying alternative ways of providing the required level of coastal protection	Monitor the level of sand available. When it is clear there will not be enough, trigger the use of the best available alternative
2b – Uncertain: There might not be enough sand transport capability	Hedging Action: • Buy an option on the private provision of sand transport boats, to be used if and when needed	Monitor the difference between the need for sand transport and the availability of boats. If the difference is too small, trigger the use of the private boat option.
3a – Uncertain: The sea level rises faster than expected	Hedging Actions: • Prepare plans for interim flood protection (e.g., station empty oil tankers along the coast)	Monitor changes in the sea level. In case of faster rise in sea level, implement interim flood protection.
3b – Uncertain: A storm surge might occur	Hedging Actions: • Provide the public with insurance against this eventuality • Prepare flood preparation and response plans	Monitor storm surge possibilities. In case of storm surge, implement flood preparation and/or flood response plans.
4 – Uncertain: The decisionmaking process on the final norm takes a long time (e.g., because of multiple and conflicting objectives among the crucial stakeholders)	Hedging Action: • Prepare emergency ‘national flood security law’	Monitor both changes in the sea level and negotiations on the new norm. In case of a trigger (rise in sea level while discussions are in a stalemate), implement the national flood security law and begin increasing the safety level of the dikes.

4.5 What are the advantages of adaptive policymaking compared to the more traditional approaches for handling uncertainty

Unfortunately, there is no magic bullet to protect us against future uncertainties. What adaptive policymaking does offer is a clear structure tools for thinking about and evaluating uncertainties and making explicit trade-offs. In short, while we may not be able to foresee all the consequences of an uncertain future, we can plan to protect ourselves from unforeseen contingencies.

Adaptive policymaking helps us make more robust plans by not ignoring uncertainty and acknowledging that we CANNOT know the future. Unlike the other approaches that either provide a single forecast of the future, or a range of futures, adaptive policymaking calls for taking action based on what we know, and requires a system for monitoring developments that could potentially affect the effectiveness of the chosen policy.

Another difference of adaptive policymaking with the other approaches is that it explicitly incorporates the element of time in policymaking. Whereas, other approaches are based on the notion that policymaking is a discrete one-time event, adaptive policymaking is explicitly a continuous process in time that involves changes to existing policy in response to unforeseen developments.

A third difference in the adaptive policymaking framework is the opportunity to modify policy in response to the changing preferences of stakeholders. Stakeholder support is an important ingredient in the success or failure of a policy. In traditional approaches stakeholder input is usually solicited via a stakeholder consultation. This stakeholder consultation, however, is one time input into the policymaking process. In the course of time, as the future changes and evolves, stakeholder preferences can also evolve and change. Adaptive policymaking allows for incorporating these changing preferences without throwing the entire policy overboard.

Finally, adaptive policymaking requires an explicit system for monitoring developments in the real world, and the performance of policy once it has been implemented. In all other approaches this is done, if it is done at all, on an ad-hoc bases. This ex-post monitoring of policy and the monitoring system are an integral part of the adaptive framework.

To conclude, the adaptive policymaking framework offers two primary advantages over other approaches. First, it does not ignore uncertainty; it acknowledges that we cannot know the future and bases policy on this assumption. And second, it institutionalizes the process of ex-post evaluation of policy and monitoring.

5 Conclusions

It is important to properly consider uncertainty in policy analysis, especially in problems related to climate change.

A proper consideration of uncertainty in every policy analysis is essential in order to properly inform/guide policymakers in the making of choices. This becomes doubly important when considering policies related to climate change for at least two reasons:

1. The phenomenon of climate change involves considering low-probability high-consequence events that can significantly impair our ability to respond and recover and can have long lasting effects.
2. Given the uncertainties surrounding climate change and its potential consequences, it is essential that we not base policy on the unproven assumption that climate change will occur gradually, giving us time to adapt.

Current policy analysis approaches and methods do not do a proper job of considering uncertainty, nor do they help policymakers make choices.

If uncertainty is at all considered in an analysis, it is considered using some form of sensitivity analysis, or by doing some sort of a scenario analysis. Sensitivity analysis is adequate for situations in which the level of uncertainty is low, and we already know with some confidence that we have an appropriate model for the phenomena in which are interested. In the case of climate change, our understanding of the phenomena and the models we use to represent these phenomena do not inspire much confidence.

While scenarios are better than only a sensitivity analysis (scenarios provide a range and not just appoint estimates), they are often based on expert judgements and/or some form of scientific consensus. Both of these techniques are notorious for their unreliability in accurately predicting the future. Although, in our view, scenarios are often not properly used to highlight uncertainties, we would like to note that, when properly used, scenarios can serve a useful role in highlighting uncertainties. However, for decisionmakers who have to choose among alternative policies for an unknown (and unknowable) future world, scenarios are less helpful.

An appropriate use of scenarios is to highlight the underlying uncertainties in a policy analysis, and to investigate the effect of uncertainty on the costs and benefits of different alternatives.

The current legal and administrative procedures for carrying out large infrastructure projects in the Netherlands (the Trace-MER procedure) leaves little room for a proper consideration and analysis of uncertainties.

The current procedure consists of three phases – the exploratory, planning, and implementation phases. The exploratory phase is to decide whether a problem is worth putting on the political agenda. There is, however, no requirement for an analysis of the problem itself, or the alternatives for dealing with the problem. This happens in the second phase, the planning phase. The problem, however, is that the planning phase requires a cost-benefit analysis (according to a pre-determined set of principles) of the options. There is little room for considering uncertainties in this phase.

We would suggest that the legal and administrative procedures be revised in order to allow for a more active consideration of uncertainties.

We have two specific suggestions that can help to promote a more active consideration of uncertainty. First, we would suggest that the analytical and political decisions be separated from one another. In other words, the politics should not be allowed to influence the analytic choices (in reality this is difficult). Second, we would suggest that much more attention should be given to the formulation of a problem (for whom is it a problem, why, is government intervention merited, etc.) and the investigation of alternatives during the exploratory phase of the Trace-MER procedure.

An alternative to the current procedures requires a different way of thinking about policy analysis and policymaking. We suggest using the adaptive policymaking approach as this framework.

The adaptive policymaking approach is fundamentally different from current approaches in that it explicitly acknowledges that our knowledge and understanding of phenomena is imperfect and limited; the ‘predict and act approach’ implicitly assumes (often with disastrous consequences) that our knowledge and understanding of phenomena is good enough to allow us use our predictions as a stand-in for reality and as the basis for our decisions.

An essential feature of the adaptive policymaking framework is the monitoring mechanism for monitoring developments of relevance to our policy. It is essential that this monitoring mechanism be institutionalised and embedded in the organisation that is responsible for the policy.

While the basis of this monitoring mechanism is data, it is much more than simply a data collection exercise. A monitoring mechanism involves identifying signposts and triggers for taking action to change/modify existing policy, or to even completely replace existing policy.