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Adaptive planning for climate-resilient, long-lived infrastructure

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Abbreviations

CPIA	Country Policy and Institutional Assessment
CSIR	Council for Scientific and Industrial Research
DBSA	Development Bank of Southern Africa
FEI	France Expertise Internationale
GIS	geographic information system
IRP	Integrated Resource Plan
UNEP DTIE	United Nations Environment Programme, Division of Technology, Industry and Economics
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development

1. Introduction

How concerned should investors be about the impact of climate change on their investments in long-lived infrastructure? What changes should these concerns trigger in the way investors have hitherto made decisions? These questions might seem rather theoretical, as financial institutions do not yet fully grasp the implications of climate change. However, the consequences of climate change are far-reaching enough to bring into question many angles of the investment process in long-lived infrastructure. These range from the risks and uncertainties of specific projects to the long-term planning for infrastructure needs and the design of infrastructure projects. Indeed, not only investors but also all the actors involved in the development of long-lived infrastructure have to integrate climate change into their business decisions. This is especially true of governments, which are responsible for infrastructure planning.

Most stakeholders still adopt a careful stance on the concept of climate change, without due consideration of its potential consequences. This leads to the required reforms of the investment decision-making process being underestimated. As a result, most interventions around climate change target 'easy wins' or 'low-hanging fruits', which require less capital and fewer institutional and regulatory changes and can, therefore, be implemented rapidly. Energy efficiency measures are good examples. While relevant in the short term, especially because of their high demonstration effects, these interventions are insufficient in the long term. Quite the reverse – there is a critical need to rethink the planning process to ensure that investment in long-lived infrastructure considers the challenges of climate change.[1]

Climate change places such new conditions on the global development pattern of individual countries that first movers already display massive advantages over their competitors. This is strikingly evident for industrial development, where many countries convincingly support green sectors as new growth opportunities. It seems far less obvious for what still constitutes the mainstay of long-term development, sustained economic growth and poverty alleviation: long-lived infrastructure. Infrastructure generally has a lifespan of at least 20 years. Much existing and planned infrastructure will still be in use by 2030 or 2050, when climate change might have a far more significant impact than it has today (IPCC, 2007). Furthermore, the different spheres of government have been and will remain both planners of and major investors in long-lived infrastructure, along with private investors. Consequently, climate change must be a primary concern at both national and local levels (for devolved issues), when they plan, design, build, operate and maintain infrastructure.

This paper does not address this very complex question directly but simply tries to unravel the additional layer of complexity represented by climate change uncertainties. It argues

1 Climate change is the main focus of this paper. However, there is a critical need to include broader environmental concerns in the planning process, ensuring the efficient use of resources and, thus, decoupling economic growth from natural resource usage.

that while it is essential to incorporate climate change uncertainties into infrastructure planning, this cannot be seen as an addition to current planning practices. The reverse is true: the planning process has to be entirely redefined, so that it can successfully integrate climate change uncertainties. Note that this paper, while presenting the changes necessary for a more efficient infrastructure planning process, does not address the governance issues related to integrated infrastructure planning, despite this being a critical dimension of efficient planning.

The next section explores the relationships between climate change and long-lived infrastructure, in terms of the different types of direct and indirect uncertainties surrounding climate change. Section 3 addresses the importance of acknowledging climate change as one of the components of the infrastructure planning process and explains how this process could be reviewed to make it more responsive to the many future uncertainties, and climate change uncertainties in particular. Section 4 concludes on the various degrees of applicability of adaptive infrastructure planning in South Africa over short to medium term.

2. Climate change uncertainties and infrastructure

What is the relationship between long-lived infrastructure and climate change? Fundamentally, the longer the lifespan of the infrastructure, the larger the impact of climate change and the lower the certainties about what these impacts will be and when they will happen. Indeed, it is clear that in the coming decades, sea levels will rise, extreme events will become more frequent and of higher magnitude, and temperature and rain patterns will evolve. But it is less clear when all these changes will happen and with what intensity.

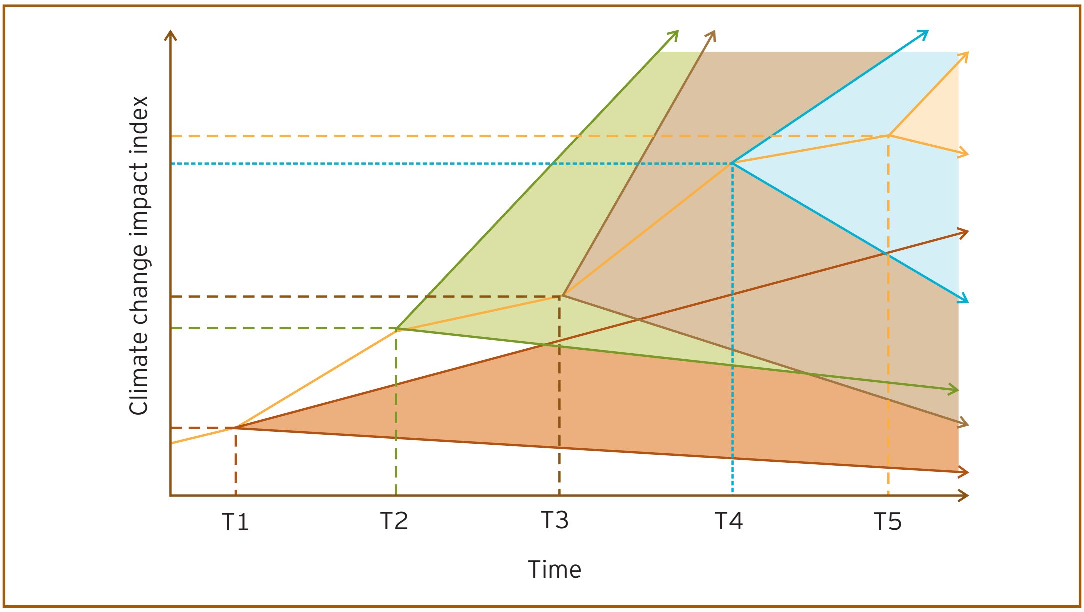
2.1 Understanding the problem

Understanding the relationships between climate change and long-lived infrastructure is crucial to addressing the challenges they entail. The first important element is the difficulty of understanding climate change uncertainties. Assume it is possible to summarise climate change impacts using a single index. On this basis, Figure 1 shows the range of possible impacts, as represented by the area between two arrows for each period T. Once the first period T has elapsed, a new range is estimated for the next one, T+1 – each universe is approximated after taking into account new sets of information accumulated during previous periods.

For the first interval, from T1 to T2, it is clear that the universe of potential impacts estimated in T1 is far too conservative, leading to a recorded climate change index for T2 out of the universe foreseen at T1. This represents the worst-case scenario, as it means that the impacts occurring in T2 have not been anticipated at all. Looking at

T3 as another example, the angle between the two arrows is wider than at T1 or T2. This expresses the possibility for additional information to increase the range of uncertainties around potential climate change impacts. As mentioned by Dessai et al. (2009: 112), '3 decades of research on climate sensitivity ... have not reduced, but rather have increased, the uncertainty surrounding the numerical range of this concept'. Additional information and modelling exercises will never eliminate the uncertainties, because many are simply irreducible. However, they are needed to identify the universe, provide a better understanding of the vulnerability of any climate-influenced decision, and subsequently guide action. Consequently, any quest for certainty around climate change impacts would fail if the purpose were to adhere to the current predict-and-act approach (Lempert et al., 2004). A quest for certainty should not delay actions; what is needed is to act now while acknowledging these uncertainties.

Figure 1: The universe of climate change impacts



Source: Thierry Giordano, DBSA and FEI

The second element that needs to be considered is the time lag. The ability to estimate and acknowledge the universe of possible changes is crucial, because of the time lag between investment in infrastructure and the reduction of climate change uncertainties. Figure 2 gives examples of sectors potentially affected by climate change, where well-functioning infrastructure is crucial for efficient economic, social or environmental service delivery. Water, energy and transport are but a few examples of sectors that are already and will still be affected by climate change, albeit in different ways and at different levels.

For any infrastructure investment related to these sectors, the main question is: in the long run, will the planned infrastructure be able to deliver the level of services for which it has been built, or will it suffer from climate change impacts to the point of becoming obsolete? Any decision to commission new or retrofit and repair old infrastructure should address climate change uncertainties to be economically and socially sound. What are these uncertainties?

Figure 2: Long-lived infrastructure and vulnerability to climate change

Sectors	Timescale (years)	Exposure
Economical social buildings (e.g. Factories, schools, hospitals)	>20	+
Water infrastructure (e.g. dams, reservoirs, distribution networks)	20–300	+++
Land-use planning (e.g. in flood plain or coastel areas)	>100	+++
Coastline and flood defenses (e.g. dikes, sea walls)	>50	+++
Buildings (e.g. insulation, windows)	30–150	++
Transportation infrastructure (e.g. ports, bridges, roads, railways train stations)	30–200	+
Urban form (e.g. urban density, parks)	>100	+
Energy production and transportation (e.g. power plants, cooling systems, distribution networks)	20–70	+

Source: Adapted from Hallegatte (2009:241); Shalizi & Lecocq (2009:4).

2.2 Sources of climate change uncertainties

Because of their highly visible consequences, extreme events tend to be the main concern of many stakeholders, be they investors, owners, service providers or users. However, extreme events are but one dimension of the different uncertainties related to climate change. Other sources of uncertainties should not be overlooked. Fay et al. (2010) distinguish three different types of uncertainties related to climate change: 1) those related to the impact of climate change on infrastructure, potentially leading to service disruptions and damage to infrastructure; 2) uncertainties related to the carbon intensity (building and/or operation) of infrastructure, ultimately influenced by the price of fossil fuels and carbon; and 3) the technologies progressively developed to address the challenges of a reduction in carbon emissions and of adaptation. To these three sources can be added another, following Hallegatte et al. (2011): 4) socio-economic determinants, such as the amount of greenhouse gas emitted in the future or the capacity of societies to adapt.

2.2.1 Impacts of climate change

As noted, traditional decision-making on infrastructure investment was based on the stationarity of the climate. Stationarity means the characteristics of climate variables that affect infrastructure do not change over time, and will be the same in the future as they were in the past. Therefore, it was possible to calculate tolerances, capacities and probabilities for extreme events, and then to construct a climate risk profile for any specific infrastructure. Stationarity was deemed a reasonable assumption according to the lifespan of the infrastructure. Technical decisions were then taken to make the infrastructure resilient to some of the risks, depending on their likelihood and the costs of risk-proofing the infrastructure. However, recent climate records prove that stationarity is no longer an adequate assumption. 'Stationarity is dead', stated Milly et al. (2008). They showed, for instance, that the stationarity hypothesis is no longer valid for water management decisions. This is true for the frequency and magnitude of extreme events but, more broadly, also for any past climate pattern.

Consequently, the first category of uncertainties refers to the stochastic nature of climate patterns, and implies that adaptation measures must be developed and implemented. While climate change is a global phenomenon, its impacts are local. It is clear that, globally, temperatures will rise, although they will fall in some parts of the world. This will be accompanied by increased fluctuations over the seasons, modified rainfall and temperature patterns, and more frequent extreme events (floods, droughts, heatwaves, frost, hurricanes, etc.) of higher magnitude. However, it is not yet clear how, where, when and with what intensity these general features will affect the local level.

2.2.2 Carbon price and natural resources

The introduction of a new commodity exclusively related to climate change is responsible for another source of uncertainty about its short-term volatility and long-term value: carbon. Carbon is already priced in some countries, either through a dedicated market or through a taxation system. While there is no certainty about the general use of carbon pricing, it appears highly likely that this measure will spread across countries. In South Africa, the National Treasury plans the introduction of a carbon tax (National Treasury, 2010).

However, the real difficulty stems from the carbon market itself, which seeks to deal with an externality for which a tax would be more appropriate. It is 'a proxy market for an artificial commodity', since the price does not depend only on supply and demand but also on the regulations that define the parameters of the market (Shalizi & Lecocq, 2009: 25). This new market is difficult to understand fully for several reasons: the absence of long records of past prices, the uncertainties about policy options (tax versus market-based price), the existence of different national and regional markets, or the incompleteness of the market itself (e.g. the futures market is not deep enough), as the uncertainty about the future of the Kyoto Protocol illustrates. Consequently, investors are engaging in a learning process at the same time as they have to make projections about the evolution of the market or the level of the tax, requiring them to speculate about future climate change policies.

The South African case is particularly illustrative of these uncertainties: South Africa had no obligation under the Kyoto Protocol to reduce greenhouse gas emissions and, therefore, no external incentive to set up a carbon market or design a carbon tax. However, the government has agreed to a voluntary approach to emission reduction by commissioning its Long-Term Mitigation Scenario (DEAT, 2007); by announcing its willingness to commit to emission reduction, conditional on technical and financial support (DEA, 2009); and by planning the implementation of a carbon tax (National Treasury, 2010). The question is then: who expected such initiatives only five years ago? This is typical of the environment in which long-term investment decisions are made. Because climate change is an international issue, the only option to reduce policy uncertainty at national level would be to have a long commitment period (longer than 30 years) under the United Nations Framework Convention on Climate Change (UNFCCC) to include the carbon constraint into long-lived infrastructure investments (Shalizi & Lecocq, 2009: 26).

This is particularly relevant for infrastructure with high carbon content, as the carbon price will have a direct financial impact, mainly on the rate of return and the payback period. Consequently, different perceptions of the future price of carbon might lead to different strategies. For instance, investors anticipating an increase in carbon prices might favour low-carbon over high-carbon infrastructure, or at least add a premium related to the carbon content.

Another dimension should not be neglected: carbon-intensive infrastructure contributes to greenhouse gas emissions, thus sustaining the offsetting demand, which leads to an increase in the price of carbon. The spin-off effect will then influence the financial results of the project by raising the long-term price of carbon. The consequences might be dramatic, as the supply function is more likely to be exponential than linear.

The result of these uncertainties about the price of carbon might well be to ensure that long-lived infrastructure depends as little as possible on carbon, whether in construction or in operation. Finally, while not mentioned by Fay et al. (2010), carbon might not be the only issue. The price of all natural resources might be affected, be they oil, coal, water or land. Planning for long-lived infrastructure will have to consider this to ensure that resources are used as efficiently as possible and with restraints to make them last in the long run (UNEP, 2011).

2.2.3 Technology innovations

Innovations in climate-friendly technology are another source of uncertainty. New technology will probably emerge and influence the demand for infrastructure. This raises several issues about which strategy to adopt. Some technologies seem promising, but estimating their associated learning curve and, hence, their deployment remains difficult. Some appear harder to implement, but a breakthrough could change their dissemination at any time; others do not exist today but may be discovered tomorrow. Technologies that are now deemed efficient might become uncompetitive in delivering a service, making the corresponding infrastructure obsolete. If such a situation were to emerge before the end of the economic lifespan of the infrastructure, the financial losses could be massive.

However, the relationship is highly asymmetric, and investing in low-carbon technology is often deemed riskier than investing in carbon-intensive projects because of the uncertainty around the reliability and deployment of low-carbon technologies. While this lack of a track record encourages caution about investing in low-carbon technology, it is not clear whether to differentiate clean technology innovations from the current innovation dynamic in other sectors. The answer lies in the stimuli for innovation. One stimulus should be the long-term price of carbon. This would influence the rate of clean technology innovation (Fay et al., 2010:38), if only it were not so difficult to estimate in the long run.

2.2.4 Socio-economic and environmental determinants

Societies have already started to adapt to climate change and its consequences, voluntarily or under compulsion. In Europe, the automotive sector has had no choice but to develop vehicles with increasingly lower emissions. In China, green sectors, such as the production of solar water heaters, have taken off, stimulated mainly by the domestic market. This has made China the foremost producer of solar water heaters in the world and the country is now an exporter of this technology. The mass development of such technologies modifies the future emissions profile of the country. These socio-economic determinants – mainly the capacity to adapt and future greenhouse gas emissions – are driven by many factors, be they demographic, economic, technological, social or cultural, all of which are difficult to anticipate (Hallegatte et al., 2011).

A striking example of the lack of inclusion of such classic uncertainties can be found in the recent Gauteng Freeway Improvement Project: the current delay in implementing the tolling system highlights the fact that the considerable discontent among users following the publication of the toll prices was completely overlooked at the planning stage. Recent adaptive transport policies tend to anticipate uncertainties around users' reaction, with the development of adaptive policy on road pricing (Marchau et al., 2010).

2.3 Uncertainties, interdependencies and planning

2.3.1 Articulating climate change uncertainties

The four uncertainties – the impacts of climate change, the price of carbon, technological innovations and socio-economic determinants – cannot be seen independently, quite the reverse. They interact in a complex manner to influence mitigation and adaptation efforts, as shown in Figure 3.[2]

2 Adaptation is defined as an 'adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harms or exploits beneficial opportunities', while mitigation corresponds to 'a human intervention to reduce the sources or enhance the sinks of greenhouse gases'. unfccc.int/essential_background/glossary/items/3666.php

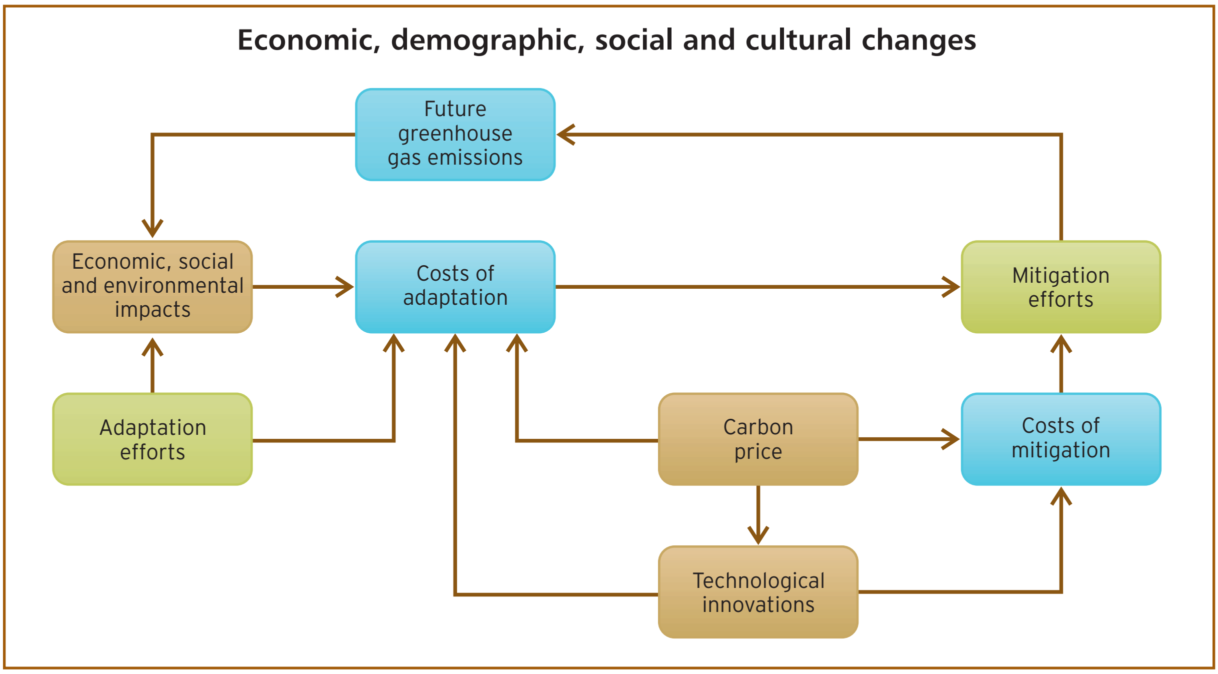
The starting point is often the mitigation efforts, especially because these were the focus of the international negotiations on the UNFCCC from the outset. These efforts determine the future global level of the greenhouse gas emissions responsible for climate change – although no clarity exists about the extent or occurrence of local impacts – which, in turn, affects adaptation requirements. At country level, the government should carry out an arbitrage operation between today's mitigation efforts and tomorrow's adaptation efforts, based on the marginal costs of each intervention, which depends on the socio-economic conditions today and tomorrow. Countries would most likely wish to estimate the impact of local mitigation efforts on climate change outcomes as part of this decision-making process. However, this trade-off is almost impossible to estimate, for the following reasons:

1. As noted, the global level of greenhouse gases depends on global efforts and not only on those of a country.
2. Estimating adaptation costs is very difficult, owing to uncertainties about the local impacts of climate change.
3. Both adaptation and mitigation costs depend on technological innovations, which are the second source of uncertainty, and socio-economic conditions.
4. Because of the different categories of uncertainties and the need to minimise conflicts between adaptation and mitigation, some adaptation actions could be highly energy-intensive and, therefore, costly if the price of carbon were to increase (Hallegatte, 2009:246).
5. The price of carbon, the third source of uncertainty, might be an incentive for further mitigation efforts and, at the same time, for developing more efficient and less costly mitigation technologies.
6. As noted, the socio-cultural and political impacts of decisions are hard to estimate, given the uncertainties involved.
7. Finally, all these dimensions are embedded into the socio-economic determinants, which control the capacity to adapt and mitigate. These determinants are very difficult to anticipate, and constitute the fourth source of uncertainty.

As a result, these uncertainties – and the way they are addressed – affect the decision-making process at the project level, but first the entire infrastructure planning process. This underlines the importance of an integrated plan. There is a two-way relationship between climate change and infrastructure: first, how infrastructure contributes to climate change and, second, how climate change affects infrastructure. For instance, many infrastructure projects are responsible for direct or indirect emissions or the reduction or capture of greenhouse gases. Coal power stations or fossil fuel-based transport infrastructure are examples of infrastructure leading to CO_2 emissions. Public transport, energy-efficient buildings or renewable energy power stations are examples of infrastructure that reduces CO_2 emissions. Parks, forest conservation and capture and storage facilities contribute to decreasing the CO_2 concentration in the atmosphere.

They are all part of a mitigation and adaptation framework and should not be seen separately. The crucial planning questions that need to be answered are what to do and when, in terms of both mitigation and adaptation.

Figure 3: Relationships between adaptation, mitigation and the four sources of uncertainty



Source: Thierry Giordano, DBSA and FEI

2.3.2 Planning long-lived infrastructure under climate change uncertainties

Investors do not always operate in isolation where long-lived public infrastructure is concerned. They mainly respond to the vision set by the government in terms of what services should be provided and when, and what infrastructure must be maintained, repaired or (re)built and when to provide the desired level of services. Consequently, the planning process is a crucial first step, which must consider the climate change uncertainties identified earlier. This is particularly true in developing and emerging countries and regions, where infrastructure needs are huge, resources are scarce, and investments must happen immediately or in the very near future. As shown by Shalizi and Lecocq (2009:5–6), at national level, most long-lived investments happen in a very short period – the so-called lumpiness of capacity installation. This leads to path dependency or lock-ins in terms of greenhouse gas emissions and/or the vulnerability of the technology to climate change. The reasons might be the high costs of retrofitting, prematurely retiring or switching to another facility once one has been installed. Furthermore, these initial disbursements might compel future investments, thus further strengthening the lock-in process.

For instance, the Integrated Resource Plan for Electricity 2010–2030 (IRP 2010–2030), adopted in March 2011, is a perfect example of both the lumpiness (as most of the investments or investment decisions will occur in the next few years) and the lock-in (since the corresponding infrastructure is intended to last for decades) (DoE, 2011). The IRP 2010–2030 is designed to respond to the increasing demand of electricity, while progressively reducing electricity production from coal, in accordance with the South African pledge at the UNFCCC. This inclusion of climate change concerns is a way to ensure the sustainability of the new infrastructure. However, as discussed later, such a plan may have major shortcomings because of its lack of adaptiveness.[3]

Another example, the Gauteng Freeway Improvement Project, might not have integrated climate change uncertainties, notably the future price of carbon. The project was designed to solve the current congestion between Pretoria and Johannesburg, and other suburban areas. It should cost R56 billion by 2030, which includes construction costs (R19.6 billion), maintenance costs and the operating costs associated with tolling (Standish et al., 2010:7). It succeeded in reducing the congestion. However, it might be responsible for a lock-in in terms of greenhouse gas emissions, unless energy efficiency norms and standards for vehicles are designed and implemented or public transport considerations (such as dedicated lanes) incorporated. An unexpected increase in the carbon price or a (non-)policy-related energy transition might also compromise the expected return on investment.

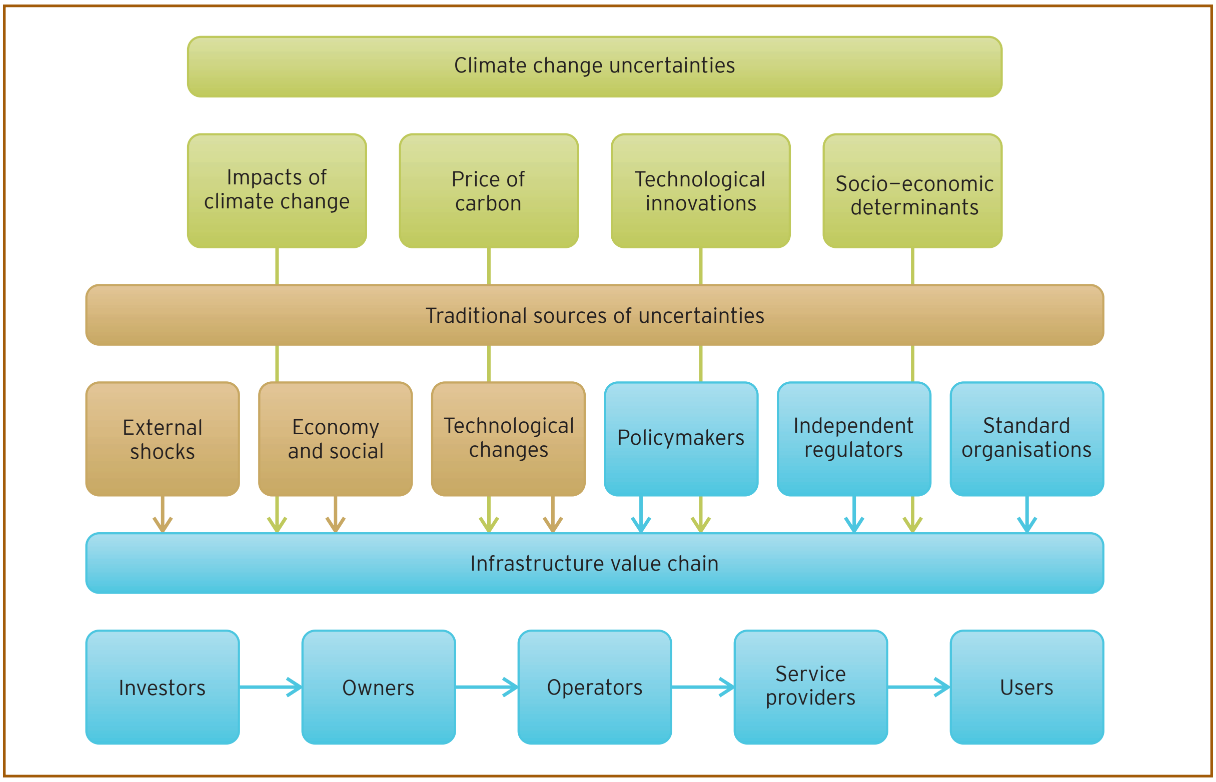
These two examples illustrate that countries need to get their infrastructure investment plan right to lay the foundation for their sustained development: priorities must be set, trade-offs made and decisions taken for critical long-lived infrastructure investments, in an external environment fraught with climate uncertainties. What is to be done? Three options can be identified (PWC, 2010:17). One would be to delay the decision until sufficient evidence exists for the decision to be considered well informed. This option might not be feasible in developing countries, where the need for new infrastructure development is urgent. Another option would be to ignore the uncertainties, because of the lack of knowledge or tools to incorporate these uncertainties in the decision-making process. The third option would be to over-engineer tolerances for a variety of potential outcomes, at greater expense. None of them are practical. Delaying the decision is impossible in emerging countries, where the need for new infrastructure is huge and represents a crucial prerequisite for poverty reduction, service delivery and future growth. Ignoring climate change uncertainties might have disastrous consequences for any investment in long-lived infrastructure. Overspending is not an option in countries where public resources are already scarce. Consequently, the entire planning process for infrastructure development has to face these uncertainties.

3 See section 3.3.

3. Innovative solutions for better planning

Climate change brings to the fore new uncertainties, which complicate an already challenging infrastructure planning process, fraught with many other social, economic and environmental uncertainties in a complex world (Figure 4).

Figure 4: Climate change uncertainties and infrastructure value chain



Source: Thierry Giordano, DBSA and FEI

In the past, planners have largely ignored all these uncertainties, given the difficulty of integrating them into the planning process. Instead, past records have been used to evaluate the likelihood of diverse events, thereby transforming uncertainties into risks. Consequently, the planning process was, and in many cases still is, based on the predict-and-act approach, which generates a recommended optimum response: the estimated future values of a set of parameters are used to predict the future, and the optimum infrastructure is defined according to this forecasting model. This method has worked well enough up to now. The traditional uncertainties – such as the future of the economy, external shocks or technology changes, to name but a few – have not led to swift or sufficiently large changes that substantially question the efficiency of investments and, hence, the very nature of the long-lived infrastructure planning process (Lempert & Groves, 2010:961).[4]

4 This is not true for more short-sighted planning processes, especially for business activities, where uncertainties caused much discussion. See, for instance, Schwartz (1998), Taleb (2008) or Goodwin and Wright (2010).

In the classic predict-and-act approach, climate was paradoxically considered as one of the rare stable parameters that could be used for planning; this is not true anymore. Climate change is a worldwide phenomenon with potentially dramatic effects. There is no way the infrastructure planning process can ignore it (Lempert & Schlesinger, 2000). 'Any infrastructure plan designed on the basis of one or a few forecasts or a small set of assumptions about the future performs poorly as a result, and unplanned ad hoc adaptations are needed to rectify this' (Kwakkel & Van der Pas, 2011:2). Therefore, climate change can be seen as a real opportunity to move toward new planning approaches, capable of integrating any kind of uncertainty. This section seeks to assess how the integrated planning process could heed climate change uncertainties for greater efficiency in service delivery by long-lived infrastructure.

3.1 Creating information to grasp uncertainties

There is no doubt that the climate is changing; countries are just struggling to anticipate how these changes will translate at the local level and what their impact will be in the coming months and years. As a result, the actual impacts of climate change might well be overlooked (Hallegatte, 2007). That is why the level and quality of information that might help to close uncertainty gaps become crucial.

Information gathering and utilisation take different forms, depending on which one of the four climate change-related uncertainties previously described is considered.

First, reducing uncertainties about the impacts of climate change and determining new probability distributions for climate patterns and events require a better understanding of 1) the potential changes in the occurrence and magnitude of extreme events; and 2) the changes in the pace or speed of incremental changes. Many climate change models have been developed around the world (IPCC, 2007) and in South Africa (Midgley et al., 2007) to improve information on the local consequences of climate change, and new generations of models are underway.[5] These will allow the identification of climate change variables and the use of historical data as a benchmark, with the inclusion of a widening deviation from the benchmark over time. This deviation captures direct, interdependent and systemic risks (related to the weakest link within systems), like a rising sea level; droughts, water scarcity and water saving; floods; heatwaves; frosts; air acidification and corrosion, and the like.

Some departments and state-owned entities have started to do exactly that.[6] The South African Risk and Vulnerability Atlas, supported by the national Department of Science and Technology and produced by the Council for Scientific and Industrial Research (CSIR),

5 See, for instance, Moss et al. (2010) for a summary of previous modelling exercises on climate change and new prospects.

6 This statement does not necessarily mean that the state should fund and/or generate this information itself. It simply implies that the state should be responsible for making this information available and accessible to the public.

is a major initiative for closing the information gap. It aims at 'equipping decision-makers with information on the impact and risk associated with global change in the region'.[7] The Atlas attempts to gather and analyse all the relevant information spread among different institutes, such as:[8]

- The toolkit for integrated planning developed by the CSIR, whose 'aim is to provide enhanced information/improved evidence as input into spatial planning and integrated development planning processes, and to support the evaluation of alternative planning decisions/policy scenarios';[9]
- The geographic information system (GIS) built by the South African National Biodiversity Institute, which provides all the relevant information about biodiversity;[10] and
- The modelling exercises done by the Climate Systems Analysis Group of the University of Cape Town on climate evolution scenarios.[11]

Aware of the importance of regional infrastructure for the development of the region, South Africa was willing to extend the Atlas to the region; this was done with the support of the United States Agency for International Development (USAID). As a result, a climate change risk and vulnerability handbook for southern Africa was released in November 2011 (Davis, 2011).

Second, and probably even more difficult to address, are the climate technology risks. What will the climate technologies of tomorrow be? At stake is the creation of knowledge about what is technically possible today and what will be possible tomorrow for both mitigation and adaptation. Several initiatives are underway to try to fill this gap. One example is the collaboration between the Development Bank of Southern Africa (DBSA) and the United Nations Environment Programme's Division of Technology, Industry and Economics (UNEP DTIE) to set up a regional network on the transfer of climate change technology, bringing together centres of excellence in the region in line with the UNFCCC negotiations on technology transfer (UNEP & DBSA, 2012). Another is the creation of a Climate Innovation Centre to stimulate clean technology innovation and entrepreneurship, which the Gauteng province is contemplating in partnership with the World Bank.[12] These two initiatives are worth noting because they complement each other, participating in knowledge creation around both technology transfer and innovation. This allows South Africa to keep up with the development, improvement and deployment of current and future environmentally sound technologies.

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7 www.rvatlas.org/
8 rava.qsens.net/data-providers
9 tip.csir.co.za/
10 biodiversityadvisor.sanbi.org/
11 www.csag.uct.ac.za/
12 1.223.69.17/cic

Third, the evolution of the carbon price depends on too many unknowns to be forecast. However, the intention of the National Treasury to introduce a carbon tax is a move in the right direction to avoid reliance on external price-setting mechanisms, such as a border carbon tax on exports, for instance. However, while this tax is set to internalise an environmental externality, it should also correct another market weakness: its short-sightedness. The carbon tax ought to be clear about the future. For example, is the tax transitory or long lasting? What will be taxed and how? When will it be revised and how? In other words, the carbon tax should be established as an adaptive policy, as described in section 3.3 below, with simple and transparent signposts that might trigger mitigation, hedging or corrective and defensive actions, as well as criteria for reassessment.

Of course, these new knowledge, information and modelling results cannot eliminate uncertainties. Indeed, improved knowledge does not necessarily mean narrower projection. This holds true for climate impacts for various reasons. 1) The 'projections of different climate models do not seem to be diminishing with time'. 2) 'Climate models are based on a set of common assumptions. The range of their results underestimates the full range of uncertainties.' 3) '[O]bservations can be dangerously misleading: [the] worst-case scenario can arise from difficulty in attributing observed changes to climate change' (Hallegatte, 2009:242). This is also true for the other sources of uncertainty. Furthermore, 'gathering information incurs a cost, and given the high level of uncertainty around climate change, significant investment in information gathering does not ensure the complete resolution of uncertainty' (PWC, 2010:20). Finally, the many methods that exist to reduce uncertainties and thereby anticipate unexpected events (be they extreme weather events, the rollout of new technologies, fluctuations in the carbon price, or economic downturns) do not seem capable of obtaining well-calibrated probabilities (Goodwin & Wright, 2010).

Consequently, generating and making use of information are a necessary condition for improved planning (which South Africa needs to pursue), but surely not a sufficient one. These new models and observations ought to assist planners in understanding the range and features of these uncertainties, and integrating them into the planning process. Being able to grasp these uncertainties will only make a difference if decision-makers can amend the planning process to heed them (Hallegatte, 2009: 242).

3.2 Acknowledging climate change as part of the planning process

In countries like South Africa, where infrastructure needs are paramount and the government is committed to investing massively in infrastructure development (R802 billion over the next three years),[13] there is little room for manoeuvre to influence the way new infrastructure is designed. As underlined by Shalizi and Lecocq (2009:2), 'this highlights the importance of limited *windows of opportunity* to shift from high-carbon to low-carbon long-lived capital stock where appropriate alternatives are or can be made available'.

13 Gordhan (2011:16).

3.2.1 Defining a long-term strategic vision

'Long-term infrastructure planning is commonly deployed throughout regulated utilities, whereby incremental infrastructure follows a Long-Term Investment Plan … which provides a framework for investment over a period of 20–40 years into the future' (PWC, 2010:20). Consequently, making infrastructure resilient to climate change is closely tied to development planning: the country needs to understand and put forward a strategic vision of the development dynamic in the coming years, so as to identify future infrastructure needs, including their spatial distribution.

The starting point of the planning process is for governments, be they national or local, to set the strategic vision for the future of their country, province or municipality. They need to be clear about what kind of medium and long-term development path they foresee (e.g. the structure of the economy, poverty and inequality targets, natural capital protection, urban versus rural population), and what developmental goals they seek to achieve (e.g. access to water and sanitation, energy, education, health, land and financial services). This strategic vision will allow them to anticipate infrastructure needs and so facilitate and support the development process. The *National Development Plan: Vision for 2030*, recently released by the National Planning Commission, attempts to shed some light in this regard (NPC, 2011). However, it remains quite a high-level document. What is still needed is the translation of Vision 2030 into an integrated investment plan for spatial infrastructure.

Notably, the national government should clearly define the critical long-term infrastructure and differentiate between existing and new infrastructure. These two categories cannot be treated in the same way. While new infrastructure should achieve an acceptable level of climate resilience, this is not necessarily the case for existing infrastructure, for at least two reasons. 1) The costs of climate-proofing the infrastructure might be extremely high relative to the services this infrastructure is expected to provide over time. 2) Economic, social and environmental services vary considerably between different types of infrastructure, some being more critical than others. For example, the economic, social and environmental consequences of a disruption of operation differ according to the type, localisation and size of the infrastructure. Consequently, the assessment process should identify, according to a fairly precise timeframe:

- Infrastructure to be maintained to ensure full operation in the long run (avoiding deficiencies);
- Infrastructure to be retrofitted to accommodate an increase in the demand for the services it needs to provide (avoiding deficiencies);
- Infrastructure to be built to respond to new needs (avoiding gaps).

The timeframe issue is crucial here: building infrastructure could take ten years and more, and new or retrofitted infrastructure must provide the right level of service at the right time:

- Too early a move into operation creates overcapacity, leading to extra costs in terms of maintenance, while the infrastructure is underutilised; however, becoming operational too late hampers the development process.
- Under-calibrated infrastructure acts as a brake on the development process, while over-calibrating leads to economic, social and environmental inefficiencies.

Furthermore, infrastructure cannot be seen in isolation, as its full effectiveness depends on the adequate operation of the other types of infrastructure surrounding it. These interdependencies, on which efficiencies in service delivery are based, require special attention to the spatial distribution of infrastructure. This implies that interdependent infrastructure should be located at the right place and be operational at the right time. Thus, the spatial dimension becomes especially important, as it frames the distribution of economic activities, the use of natural resources, the development of markets, the efficiency of the socio-economic system (Turok, 2011), and, consequently, the sustainability of society.

3.2.2 Impacts of climate change uncertainties

Once the needs have been identified in terms of both quantity and localisation, decisions must be made about the best way to respond to these needs. Critical infrastructure must be identified and a build and maintenance programme planned. The main difficulty is that climate change influences the entire framework at every stage of the planning process, including the identification of needs. Consequently, climate change uncertainties have to be part of the strategic vision. The task is highly complex: 'Infrastructures are a complex web of public and private assets, created and operated within layers of government that have varying jurisdiction over their locations, design, pricing, accessibility and general operation. How can anyone coherently address such real-world complexity?' (Hansman et al., 2006:148).

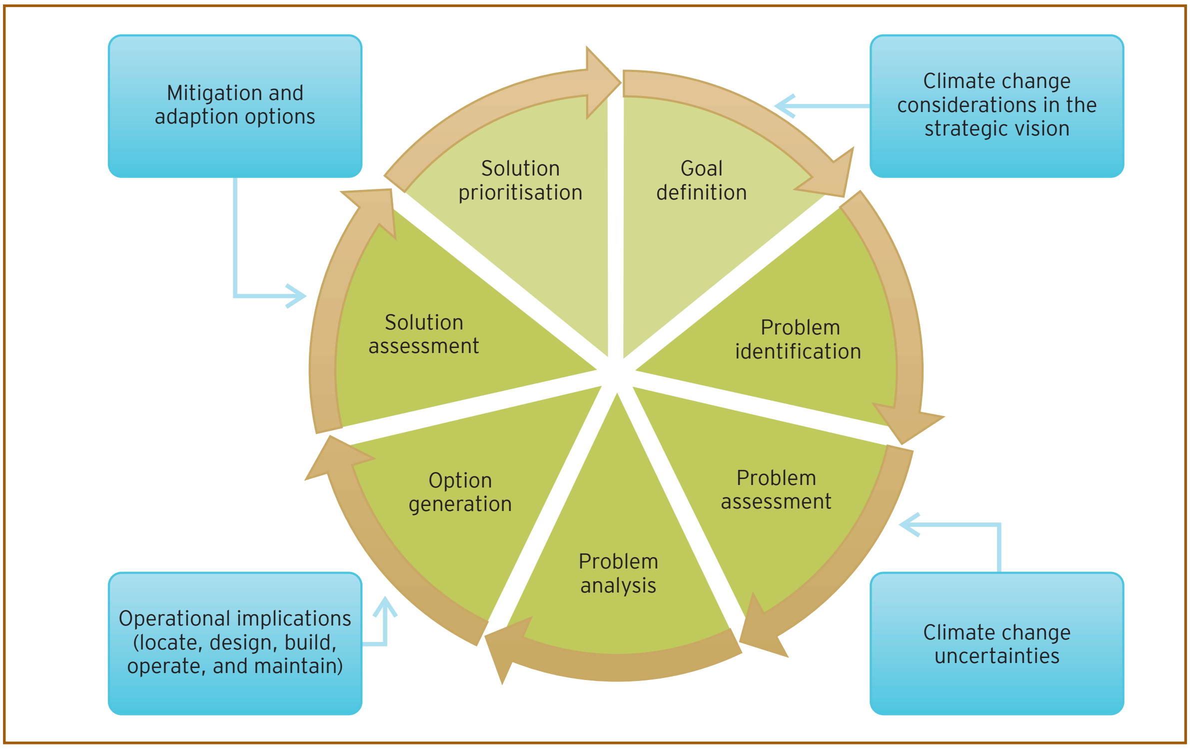
Figure 5 uses the assessment process for infrastructure planning recently used by the Australian Government to illustrate this complexity (GoAus, 2009; 2010). Climate change affects the planning process at different stages:

- Climate change must be embedded into the long-term strategic vision of the government. Many developed and emerging countries are looking towards green growth as one option for long-term development, placing the transition to a low-carbon economy at the heart of their vision. The direct implication is decoupling their growth trajectory from the use of natural resources, including fossil fuels (Winkler & Marquand, 2009; UNEP, 2011). The degree of integration of climate change concerns into the strategic vision of the government shapes the demand for infrastructure and, therefore, influences the definition of goals.
- Climate change uncertainties are additional to the traditional sources of uncertainty that influence the way the problem is framed, and are probably the most important one: 'climate change might result in irreversible damage. Due to uncertainty over

tipping points (after which climate stresses have irreversible consequences) and low-probability catastrophic events, delaying decisions might lead to irreversible damage' (PWC, 2010:20). However, as noted, they are not the only ones; many uncertainties are actually overlooked during the planning process. Climate change can be seen as an opportunity to review how the problem assessment is conducted.

- The options emerging from the analysis have numerous implications in terms of the location of the infrastructure, its design, the way it is built, its operational capacity and efficiency, and the level of maintenance required. For each type of infrastructure, the potential impact of climate change should be considered and the timing of the intervention should be determined. Consequently, 'the analysis requires a good understanding of when the cut-off points will occur. An inaccurate estimate of these points would ultimately affect the outcomes of the appraisal' (PWC, 2010:20).
- Finally, the solutions identified ought to integrate different mitigation and adaptation options.

Figure 5: Infrastructure needs assessment and the influence of climate change



Source: Adapted from GoAus (2010).

3.3 Introducing flexibility and adaptiveness into the planning process

Once the uncertainties around climate change have been acknowledged, the planning process needs to move away from classic planning from the outset to introduce flexibility and adaptiveness/correctability into the process itself.

3.3.1 Dynamic adaptive planning in theory

Such an approach is based on the work developed around the concept of adaptive policy. Defining policy as adaptive means that this policy 'is devised not to be optimal for a best estimate future, but robust across a range of plausible futures' and 'responds to changes over time and makes explicit provision for learning' (Walker et al., 2001:283). It acknowledges the 'high degree of interconnectedness and dynamic consequences' in a world where 'unpredictability and the presence of unknown unknowns are the underlying traits' (Swanson et al., 2010:926).

These new planning methods call for different kinds of information compared to that required by a probabilistic optimisation process. At stake is not to translate uncertainties into risks, but to 'provide the range of what is possible and of what is probable, and quantitative information about when observations will be able to discriminate between several scenarios' (Hallegatte, 2009:243).

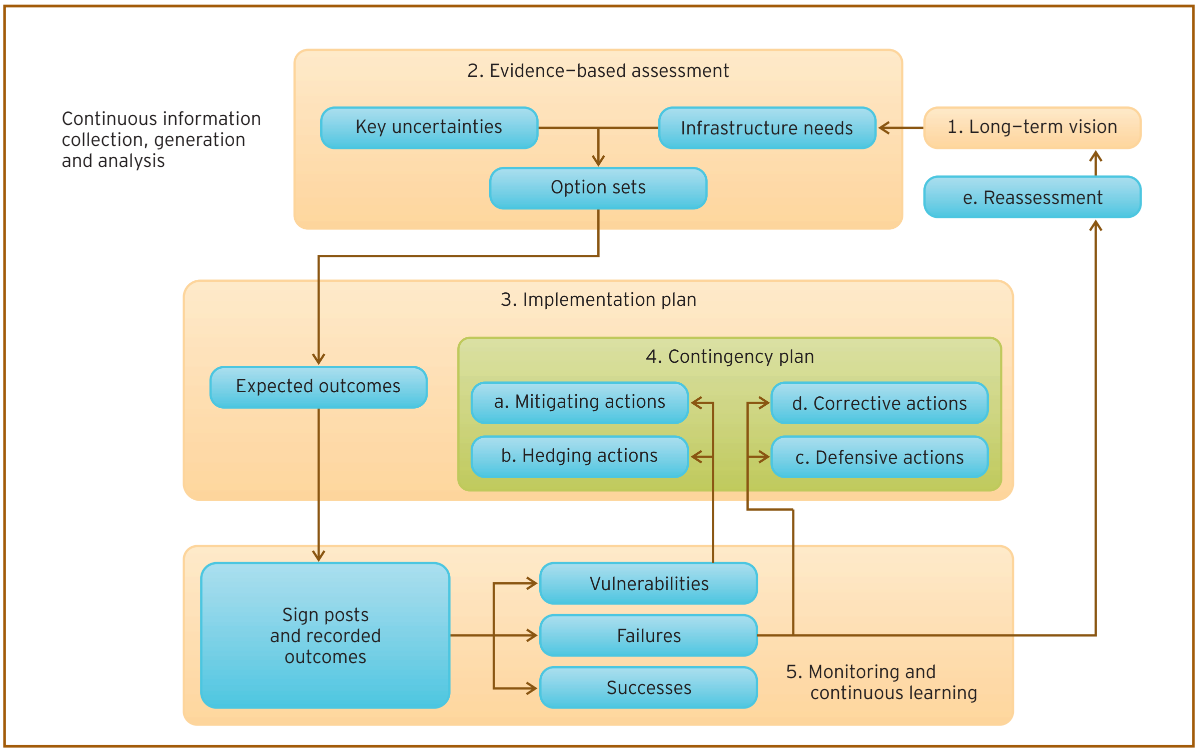
Drawing heavily on Walker et al. (2001:285–7) and their concept of adaptive policy, this paper outlines how an adaptive planning process can be designed to lead to a dynamic adaptive plan for infrastructure development. Such a plan will evolve over time, according to the permanent flow of information that feeds the planning process. Figure 6 presents a five-stage adaptive planning process, which can be described as follows (the first two stages have been developed in previous sections and are merely summarised):

1. *Long-term vision:* The starting point is the long-term vision the government has defined for the country, considering, among other factors, new uncertainties created by climate change.
2. *Evidence-based assessment:* From this vision, infrastructure requirements are determined. Several options can be defined to meet these requirements; the government will then decide which one seems most appropriate.
3. *Implementation plan:* The expected outcomes are clearly framed, and the plan is implemented.
4. *Contingency plan:* The implementation plan includes a contingency plan with different types of adaptive measures to ensure the infrastructure requirements are met (Walker et al., 2001:285). They must be explicit from the outset to avoid any forced review process happening on an ad hoc – and, therefore, uncertain – basis. These measures will then be triggered as and when needed, according to the availability of information:
    a. *Mitigation actions:* Actions taken *in advance* to reduce adverse effects, which were anticipated but not certain at the planning stage;
    b. *Hedging actions:* Actions taken *in advance* to reduce the risk of *possible* adverse effects that have newly been identified;
    c. *Defensive measures:* Actions taken after a risk has materialised, but the damages are such that the plan does not need to be modified;

   d. *Corrective actions:* Actions taken after a risk has materialised, but the damages are such that part of the plan has to be modified; and
   e. *Reassessment:* The plan is clearly not working and needs to be reassessed. The government has no option other than to redefine its vision and infrastructure requirements.

5. *Monitoring, continuous learning and improvement:* Signposts – defined as unintended social, economic and environmental impacts – and outcomes are monitored to identify successes, vulnerabilities and failures. They are responsible for triggering adaptive measures if the recorded impacts fail to meet the expected outcomes.

Figure 6: A dynamic adaptive integrated infrastructure planning process.



Source: Adapted from Walker et al. (2001:286).

Thereby, adaptive, integrated infrastructure planning moves away from the mere prediction and control paradigm to embrace a 'learning by judicious doing' approach to avoid any catastrophic and irreversible error (Swanson et al., 2010:925). As a result, because of the deep uncertainties around climate change and the impossibility of achieving consensus on them, the contingency plan becomes the crucial element around which decision-making will converge, since it is designed to respond to any kind of future climate (Lempert & Groves, 2010:961).

Robust decision-making appears a promising tool to define adaptive strategies. The basic idea is to subject a policy to a variety of different future scenarios to evaluate its performance, which makes robust decision-making a synthesis between scenario planning and quantitative analysis (Lempert & Schlesinger, 2000:391). Lempert & Groves (2010:961) define robust decision-making as follows: '[It] is a particular approach of a broader class of robust decision methods. In contrast to many decision analytic approaches, these methods treat uncertainty with multiple, rather than single, views of the future and evaluates alternative strategies with a robustness, rather than an optimality, criterion.' Lempert & Groves (2010) applied this methodology to a water agency in the United States to demonstrate under what circumstances their strategy would perform poorly and what could be done to improve its resilience.

3.3.2 Operationalising adaptive planning

New planning methods that seek to address deep uncertainties, such as those related to climate change, are very appealing on paper, but rarely applied in practice. Several reasons could be put forward, including the limited assessment of the validity and applicability of these new planning approaches (Kwakkel & Van der Pas, 2011:2) or the limits of forecasting methods (Goodwin & Wright, 2010). However, between the too simplistic predict-and-act planning method and what could be an extremely complex dynamic adaptive planning approach, it is possible to identify several thrusts that could be followed both by national and local governments.

First, despite many endeavours to gather observations and design more accurate models, the four sources of uncertainty will persist in the coming decades. Infrastructure plans should acknowledge these uncertainties, identify the resulting vulnerabilities, and anticipate what should be done when these uncertainties materialise. Mainstreaming climate change into the three spheres of government is a means to put pressure on decision-makers and force them to consider climate change uncertainties.

Second, because identifying vulnerabilities requires an assessment of a variety of futures, scenario planning becomes an important tool to introduce adaptiveness and flexibility into the planning process. Scenario planning is a complex matter, which has seen many developments over the past decades and the emergence of many methodologies (Bradfield et al., 2005). The core steps of the scenario planning process remain the identification of the following (Schwartz, 1998:101–17; Swanson et al., 2010:928–99):

- The driving forces or most important factors influencing the planning process (society, economics, technology, politics and environment);
- The predetermined factors or factors that are most certain and can be treated as risks, if necessary; and
- The critical uncertainties that will constitute the focus of the scenario analysis.

Scenario planning appears to be a useful tool for national, integrated infrastructure planning: critical infrastructure needs must be identified; major risks, uncertainties and vulnerabilities assessed; technology choices set; spatial build and maintenance programmes defined; contingency plans drawn; and the learning process included. The government should send clear signals about the importance of climate-resilient infrastructure. This has to be translated into regulations, policies, guidelines and operating frameworks to facilitate the planning process at local level.

Once the national plan is well established, the tasks of local authorities would become much easier, as the main concerns would then be related to uncertainties around climate impacts. A well-defined accompanying programme would be crucial to facilitate the inclusion of adaptation plans into local infrastructure development plans. According to Ford et al. (2011:330), 'institutional guidelines and governmental mechanisms' are the most common programmes implemented in developed countries to facilitate adaptation at local level. For instance, a review of the *Guidelines for compiling comprehensive infrastructure plans for municipalities*, edited by the then Department of Provincial and Local Government, is needed (DPLG, 2008:6–7). It currently relies on the principle of predict-and-act: spatial development planning, coupled with a demographic model, forms the basis of the identification of infrastructure needs. The inclusion of climate uncertainties becomes crucial for the long-term sustainability of infrastructure investments and efficient service delivery.

The challenge is then to ensure that local authorities consider both climate change uncertainties and their consequences, and the available tools to deal with them. Reviewing the literature on adaptation actions taken by developed countries to cope with climate change, Ford et al. (2011:334–5) found that discourses are seldom translated into concrete action:

> 'A major challenge highlighted in a number of articles concerns the lack of political will to meaningfully address climate change impacts, particularly at local levels where a mismatch between national statements on adaptation and local action has been noted. In such cases, adaptation interventions have preferred short-term risk reduction over long-term strategic planning, potentially increasing vulnerability and making future adaptation more difficult. Institutional barriers, along with limited consideration of future climate scenarios in adaptation intervention, create potential for maladaptation.'

Such challenges must not be overlooked. Today, a few metros or municipalities have managed to push the climate change agenda forward, like eThekwini (Roberts, 2010), Cape Town (Mukheibir & Ziervogel, 2007) and Johannesburg. Many studies exist, both general or sectoral, such as on the impact of climate change on water resource planning in Polokwane (Cullis et al., 2010) or on the consequences of climate change in rural areas (Quinn et al., 2011), to mention but a few. However, it is not clear how influential these studies would be in translating academic research into concrete actions. Furthermore, in poorer and smaller municipalities, there is a dire need for support. To turn things around, the mainstreaming of climate change in policymaking becomes a crucial prerequisite. Many recent national policy papers have highlighted the importance of considering climate change in the development process.[14] However, there are still doubts about the ability of the current institutional framework to allow an adequate integration of climate change concerns into decision-making by the three spheres of government (Giordano et al., 2011).

3.4 Climate-resilient decision-making options

Ultimately, the adaptive planning process leads to investment decisions. Several options are available to cope with uncertainties related to climate change (Hallegatte, 2009:244–6; PWC, 2010:42):

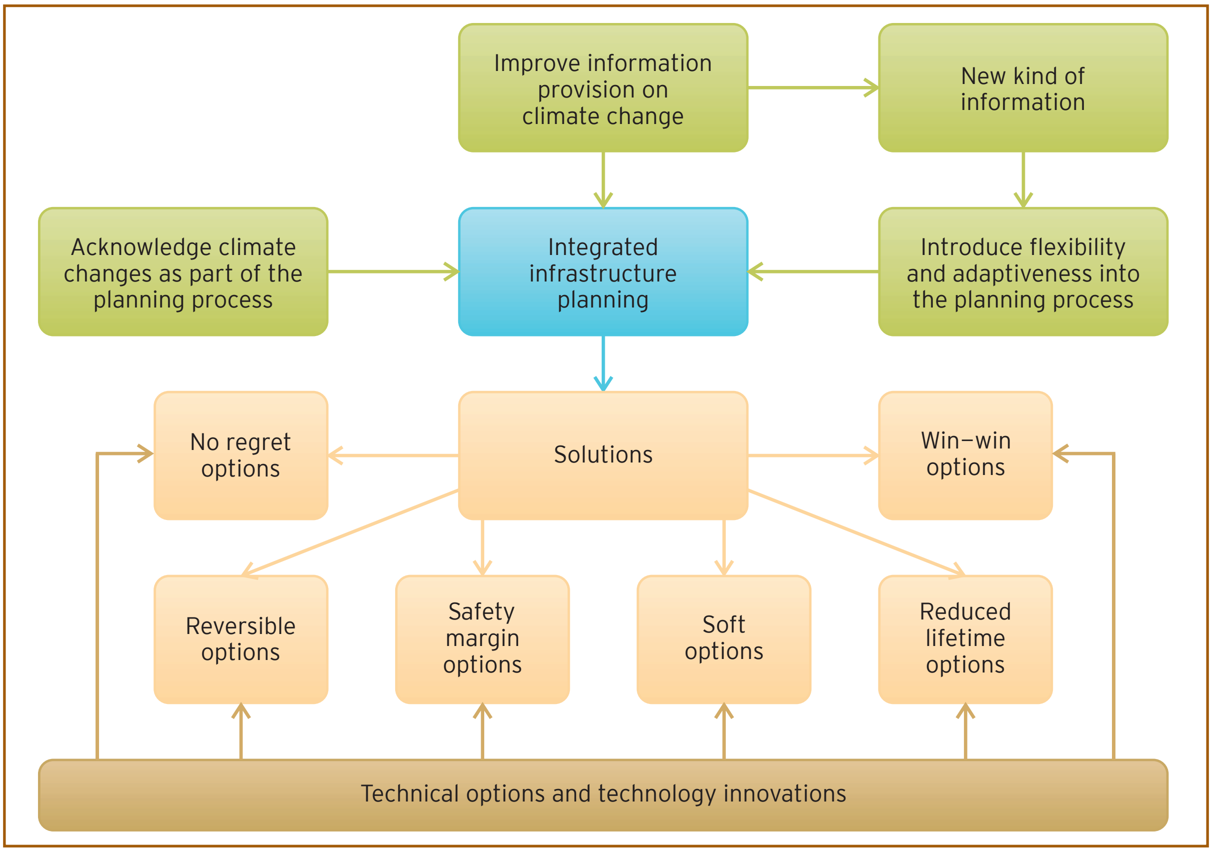
- *No (or low) regret options:* The purpose is to find solutions that are not climate sensitive or are 'judged to provide sufficient or alternative benefits regardless of the outcome of the climate scenario measures' (PWC, 2010:42). While appealing in theory, there are not many options in practice.
- *Reversible and flexible options:* This strategy is closely linked to the decision pathway or 'real option approach', which emphasises the possibility of delaying a decision. 'Adopting a decision pathway or having a "real option" means building in the possibility at a certain period in the lifetime of a project to make a decision without committing to this at the beginning. In practice, the decision pathway approach and [the real option approach] incorporate a dynamic learning mechanism which provides the opportunity to phase investments and stage key decisions, to assess the costs and benefits of options at a later stage, for example by:
  - Investing now and making follow-up investments later, subject to the progress of the original project (a growth option);
  - Abandoning the project if losses outweigh the benefits (an exit option); and
  - Waiting and learning before investing (a timing option)' (PWC, 2010:43).
- *Safety margin options:* These strategies are based on the fact that the costs of integrating climate concerns during the design phase of an infrastructure project might be far lower than modifying it once it has been built. The cost of including this security margin is the key determinant of the decision, and the trade-off has to be between this cost and the reversibility of the decision – one might accept a higher cost when the decision is irreversible.
- *Soft options with limited hard consequences:* This relates to the use of institutional and financial tools instead of large investments. Insurance and early warning and evacuation

14 See, for example, the New Growth Path (EDD, 2011), the National Climate Change Response White Paper (DEA, 2011) and the National Development Plan (NPC, 2011).

systems are the two most common soft options; only insurance can be applied to infrastructure. Its main advantage is the flexibility of the system, as insurance premiums are defined every year and can be adjusted as needed. The trade-off of using a soft option is between the economic, social and environmental consequences of having infrastructure damaged and the service disrupted (including the insurance premium), and the costs of protecting the infrastructure.

- *Reduced investment's lifetime option:* The level of uncertainty about climate change increases with time. Building infrastructure that provides a service for only ten years might be more prudent than building infrastructure that will provide the same service for 50 years.
- *'Win-win' options:* The objective is to respond to climate change while, at the same time, providing one or more services. Thus, the cost of climate change actions is mitigated by the savings from not having to provide the joint services, rendering these climate change measures more acceptable. Another win-win situation occurs when infrastructure changes act as both mitigation and adaptation options. Hallegatte (2009:246) mentions building insulation as both an adaptation measure to temperature changes (long-lasting frosts or heatwaves) and a mitigation measure, as it will lead to energy savings, especially when this energy has a high carbon content.

Figure 7: Generic climate-resilient planning process and climate-resilient options



Source: Thierry Giordano, DBSA and FEI

4. Conclusion

Adaptive planning is a recent field of work. Further research is needed to understand fully how such an approach could be efficiently adapted and used in South Africa. Nevertheless, it is true to say that climate change poses a significant challenge to long-lived infrastructure investments, as the level of uncertainty surrounding its impacts cannot be compared to any other source of uncertainty. This means that the infrastructure planning process must be profoundly revisited. This paper highlighted the different sources of uncertainty related to climate change and explained why the classic predict-and-act approach appears highly questionable.

Several measures could be taken to improve the planning process. First, there is a need to gather as much information as possible to determine what is known, or not, about climate change, capturing the different sources of uncertainties. Efforts are underway to close these knowledge gaps, and thereby improve the characterisation of these uncertainties. The national government needs to send the right signals to minimise uncertainties over which it has some influence, like the price of carbon. It should also foster the provision of relevant information to help stakeholders understand the challenges of climate change.

Second, once characterised, the importance of dealing with these uncertainties must be acknowledged as an integral part of the planning process and, therefore, the strategic long-term vision for the country. Scenario planning forms the mainstay for evaluating policies according to several plausible futures. Robust decision-making, which couples scenario planning and quantitative analysis, might then be a powerful tool to measure the performance of various investment plans and to design coping strategies.

Third, the planning process ought to demonstrate a high level of flexibility over time to be able to respond to these uncertainties. This may be too complex to be fully operationalised in the short term; what is reasonable to expect as first steps has to be highlighted. For instance, an efficient climate change mainstreaming strategy among the three spheres of government, an adapted institutional framework, and a comprehensive set of regulations and guidelines would greatly facilitate the inclusion of climate change concerns into planning processes for local infrastructure.

Finally, this adaptive plan should translate into concrete, climate-resilient investment decisions to limit the potential negative impacts or exploit the potential positive impacts of climate change on the quality and level of services that long-lived infrastructure has been planned to provide.

For such an approach to succeed, more needs to be done to support local authorities. Many tools already exist to support the development of the Integrated Development Plans. These tools need to be evaluated and reviewed to include climate change concerns.

5. References

Bradfield, R, Wright, G, Brut, G, Cairns, G & Van der Heijden, K, 2005. The origins and evolution of scenario techniques in long range business planning. *Futures*, 37:795–812.

Cullis, J, Strzepek, K, Tadross, M, Sami, K, Havenga, B, Gildenhuys, B & Smith, J, 2010. Incorporating climate change into water resources planning for the town of Polokwane, South Africa. *Climatic Change*, 108:437–56.

Davis, C, 2011. *Climate risk and vulnerability – A handbook for southern Africa.* www.sarva.org.za/sadc/download/sadc_handbook.pdf

DEA (Department of Environmental Affairs), 2009. *President Jacob Zuma will attend climate change talks in Copenhagen.* Department of Environmental Affairs media statement, 6 December. www.environment.gov.za//NewsMedia/MedStat/2009Dec6/medStatmnt-06122009.pdf

DEA (Department of Environmental Affairs), 2011. *National Climate Change Response White Paper*. www.environment.gov.za/PolLeg/WhitePapers/national_climatechange_response_whitepaper.pdf

DEAT (Department of Environmental Affairs and Tourism), 2007. *Long-term mitigation scenarios: Strategic options for South Africa*. Pretoria: DEAT. www.environment.gov.za/HotIssues/2008/LTMS/LTMS.html

Dessai, S, Hulme, M, Lempert, R & Pielke, R Jr, 2009. Do we need better predictions to adapt to a changing climate? *Eos*, 90(13):111–2.

DoE (Department of Energy), 2011. *Integrated Resource Plan for Electricity 2010–2030.* Final report, Revision 2, 25 March. www.doe-irp.co.za/content/IRP2010_2030_Final_Report_20110325.pdf

DPLG (Department of Provincial and Local Government), 2008. *Comprehensive Infrastructure Planning Framework for achieving sustainable municipal service delivery.* Document CIP-00. www.thedplg.gov.za/cip/documents/CIP-00%20Overview.doc

EDD (Economic Development Department), 2011. *The New Growth Path.* www.environment.gov.za/PolLeg/WhitePapers/national_climatechange_response_whitepaper.pdf

Fay, M, Limi, A & Perrissin-Fabert, B, 2010. Financing greener and climate-resilient infrastructure in developing countries – Challenges and opportunities. *EIB Papers*, 15(2):35–58. www.eib.org/attachments/efs/eibpapers/eibpapers_2010_v15_n02_en.pdf#page=36

Ford, JD, Berrang-Ford, L & Paterson, J, 2011. A systematic review of observed climate change adaptation in developed nations. *Climatic Change*, 106:327–336.

Giordano, T, Hall, L, Gilder, A & Parramon, M, 2011. *Governance of climate change in South Africa.* Pretoria: Department of Environmental Affairs (DEA). www.environment.gov.za/research/climate_change_governance.pdf

GoAus (Government of Australia), 2009. *National infrastructure priorities – Infrastructure for an economically, socially, and environmentally sustainable future*. Canberra: GoAus. www.infrastructureaustralia.gov.au/publications/files/National_Infrastructure_Priorities.pdf

GoAus (Government of Australia), 2010. *Better infrastructure decision-making: Guidelines for making submissions to Infrastructure Australia's infrastructure planning process, through Infrastructure Australia's Reform and Investment Framework.* www.infrastructureaustralia.gov.au/reform_investment/files/Better_Infrastructure_Decision_Making_Guidelines.pdf

Goodwin, P & Wright, G, 2010. The limits of forecasting methods in anticipating rare events. *Technological Forecasting and Social Change*, 77:355–68.

Gordhan, P, 2011. *Medium-Term Budget Policy Statement.* www.treasury.gov.za/documents/mtbps/2011/mtbps/speech.pdf

Hallegatte, S, 2007. Do current assessments underestimate future damages from climate change? *World Economics*, 8(3):131–46.

Hallegatte, S, 2009. Strategies to adapt to uncertain climate change. *Global Environmental Change*, 19:240–47.

Hallegatte, S, Przyluski, V & Vogt-Schlib, 2011. Building world narrative for climate change impact, adaptation and vulnerability analyses. *Nature Climate Change*, 1:151–5.

Hansman, RJ, Magee, C, De Neufville, R, Robins, R & Roos, D, 2006. Research agenda for an integrated approach to infrastructure planning, design and management. *International Journal of Critical Infrastructures*, 2(2/3):146–59.

IPCC (Intergovernmental Panel on Climate Change), 2007. *Climate change 2007.* Fourth Assessment Report of the IPCC. Cambridge University Press: IPCC.

Kwakkel, JH & Van der Pas, JWGM, 2011. Evaluation of infrastructure planning approaches: An analogy with medicine. *Futures*, forthcoming.

Lempert, RJ & Groves, DG, 2010. Identifying and evaluating robust adaptive policy responses to climate change for water management agencies in the American West. *Technological Forecasting and Social Change*, 77:960–74.

Lempert, RJ & Schlesinger, ME, 2000. Robust strategies for abating climate change. *Climate Change*, 45:387–401.

Lempert, RJ, Nakicenovic, N, Sarewitz, D & Schlesinger, M, 2004. Characterizing climate-change uncertainties for decision-makers. *Climate Change*, 65:1–9.

Marchau, VAWJ, Walker, WE & Van Wee, GP, 2010. Dynamic adaptive transport policies for handling deep uncertainties. *Technological Forecasting and Social Change*, 77:940–50.

Midgley, G, Chapman, R, Mukheibir, P, Tadross, M, Hewitson, B, Wand, S, Schulze, R, Lumsden, T, Horan, M, Warburton, M, Kgope, B, Mantlana, B, Knowles, A, Abayomi, A, Ziervogel, G, Cullis, R & Theron, A, 2007. *Impacts, vulnerability and adaptation in key South African sectors: An input into the Long-Term Mitigation Scenarios process.* Long-Term Mitigation Scenarios (LTMS) Input Report 5. www.environment.gov.za/hotissues/2009/LTMS2/ImpactsVulnerabilityAdaptation.pdf

Milly, PCD, Betancourt, J, Falkenmark, M, Hirsch, RM, Kundzewicz, ZW, Lettenmaier, DP & Stouffer, RJ, 2008. Stationarity is dead: Whither water management? *Science*, 319:573–4.

Moss, RH, Edmonds, JA, Hibbard, KA, Mannong, MR, Rose, SK, Van Vuuren, DP, Carter, TR, Emori, S, Kainuma, M, Kram, T, Meehl, GA, Mitchell, JFB, Nakicenovic, N, Riahi, K, Smith, SJ, Stouffer, RJ, Thomson, AM, Weyant, JP & Wilbanks, TJ, 2010. The next generation of scenarios for climate change research and assessment. *Nature*, 463:747–56.

Mukheibir, P & Ziervogel, G, 2007. Developing a Municipal Adaptation Plan (MAP) for climate change: The city of Cape Town. *Environment and Urbanization*, 19(1):143–58.

National Treasury, 2010. *Reducing greenhouse gas emissions: The carbon tax option.* National Treasury discussion paper for public comments. www.treasury.gov.za/public%20comments/Discussion%20Paper%20Carbon%20Taxes%2081210.pdf

NPC (National Planning Commission), 2011. *National Development Plan: Vision for 2030.* www.npconline.co.za/medialib/downloads/home/NPC%20National%20Development%20Plan%20Vision%202030%20-lo-res.pdf

PWC (PricewaterhouseCoopers), 2010. *Adapting to climate change in the infrastructure sectors – Maintaining robust and resilient infrastructure systems in the energy, transport, water and ICT sectors.* archive.defra.gov.uk/environment/climate/documents/infrastructure-pwc-full.pdf

Quinn, CH, Ziervogel, G, Taylor, A, Takama, T & Thomalla, F, 2011. Coping with multiple stresses in rural South Africa. *Ecology and Society*, 16(3):2-1–2-20.

Roberts, D, 2010. Prioritizing climate change adaptation and local level resilience in Durban, South Africa. *Environment and Urbanization*, 22(2):397–413.

Schwartz, P, 1998. *The art of long view – Planning for the future in an uncertain world*. Chichester: John Wiley & Sons Ltd.

Shalizi, Z & Lecocq, F, 2010. *Climate change and the economics of targeted mitigation in sectors with long-lived capital stock.* World Bank Policy Research Working Paper 5063, Background Paper to the 2010 World Development Report. Washington, DC: World Bank. siteresources.worldbank.org/DEC/Resources/84797-1257266550602/Lecocq.pdf

Standish, B, Boting, A & Marsey, A, 2010. An economic analysis of the Gauteng Freeway Improvement Scheme. Report prepared for the Provincial Government of Gauteng and the South African National Road Agency (Pty) Ltd. www.sanral.co.za/content/Gauteng_GFIP_final_economic_report.pdf

Swanson, D, Barg, S, Tyler, S, Venema, H, Tomar, S, Bhadwal, S, Nair, S, Roy, D & Drexhage, J, 2010. Seven tools for creating adaptive policies. *Technological Forecasting and Social Change*, 77(6):924–39.

Taleb, NN, 2008. *The black swan: The impact of the highly improbable.* London: Penguin Books.

Turok, I, 2011. *The case for a national spatial vision.* Mimeo, February.

UNEP (United Nations Environment Programme), 2011. *Decoupling natural resource use and environmental impacts from economic growth.* A Report of the Working Group on Decoupling to the International Resource Panel. www.unep.org/resourcepanel/decoupling/files/pdf/Decoupling_Report_English.pdf

UNEP (United Nations Environment Programme) & DBSA (Development Bank of Southern Africa), 2012. *Southern African Network for Accelerating Investments in Climate Technology Transfer (SANAICTT).* Revised draft concept note. Mimeo, March.

Walker, WE, Rahman, SA & Cave, J, 2001. Adaptive policies, policy analysis, and policy making. *European Journal of Operational Research*, 128:282–9.

Winkler, H & Marquand, A, 2009. Changing development paths: From an energy-intensive to low-carbon economy in South Africa. *Climate and Development*, 1:47–65.