FCFA Applied Research Fund: Economics, Political Economy and Behavioural Science of Accounting for Long-term Climate in Decision Making Today

Review Phase

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Note: This literature review was prepared to inform the above project. It is published here in draft form to contribute to grey literature on this topic, and has not been peer reviewed.

GCAP, Vivid Economics, UK Met Office and Atkins

FCFA Applied Research Fund: Economics, Political Economy and Behavioural Science of Accounting for Long-term Climate in Decision Making Today

This report summarises the findings of Phase 1 of the project '*Economics, Political Economy and Behavioural Science of Accounting for Long-term Climate in Decision Making Today*'. The study is being undertaken by the Global Climate Adaptation Partnership (GCAP), working with Vivid Economics, the UK Met Office and Atkins.

SUMMARY

This report summarises the findings of Phase 1 of the project '*Economics, Political Economy and Behavioural Science of Accounting for Long-term Climate in Decision Making Today*'. The study is being undertaken by the Global Climate Adaptation Partnership (GCAP), working with Vivid Economics, the UK Met Office and Atkins.

This project is one of a number of research activities that have been commissioned by the Future Climate For Africa (FCFA) programme, which is advancing scientific understanding of sub-Saharan African climate on decadal timescales and promoting the use and uptake of climate information in long-term climate-resilient development strategies.

The aims of the current project are to analyse and identify the types of development decisions that should be actively accounting for future (10 years+) climate in decisions taken today, and to advance quantitative evidence on this to help inform decisions made by development practitioners in Africa.

The aims of the first phase of the project – summarised in this report – are to undertake an initial literature review on long-lived policies, to identify practical examples of long-term decisions, and to review the barriers to long-term decision-making. The findings of these tasks will be used to provide initial conclusions and develop a framework and methodology for phase 2, which will undertake a series of economic case studies.

The findings of the report are summarised below.

TASK 1: IDENTIFICATION OF LONG-LIVED POLICIES AND INVESTMENTS

This task has explored a number of evidence lines to identify where and how long-lived polices, plans and investments are being made across sub-Saharan Africa and where these will shape vulnerability.

Policy review
The study has first reviewed the potential areas of interest for the study. This builds on earlier work of Hallegatte and Ranger, which indicates a potential focus for infrastructure (water,

irrigation and flood protection infrastructure, but also energy and transport infrastructure) and planning (especially urban and coastal planning), in the 5 to 40 year period of interest for the study. However, additional review highlights that even in these cases, the picture is likely to be more nuanced, for example while major hydropower schemes might justify climate risk screening, smaller hydropower plants may not, and the justification for investment in road schemes might be limited to siting and critical nodes (bridges). The review has also identified some additional areas that are relevant for this time period. This includes forestry, agricultural land-use and crop planning (especially key export crops) and natural and semi-natural ecosystem management.

Development planning review
In addition to the review above, the study has also identified the types of processes that are involved in medium-long-term adaptation, as these are critical in looking at practical implementation. In the adaptation context – in Sub-Saharan Africa – this is centred on adaptation mainstreaming, i.e. the integration of adaptation into existing development planning processes (and sectors) and the inclusion in programme and project safeguard and screening processes. The focus on mainstreaming, however, creates a set of additional problems, associated with the transfer of potential complex medium to long-term adaptation decisions to sectors and actors. A number of recent reviews have investigated these issues, and highlighted some practical recommendations, which are summarised.

Economic scoping
In many cases, the most important impacts of climate change are likely to arise in the future. The benefits of adapting to these changes accumulate over long, future time horizons, while the costs are incurred now. Using the discount rates conventionally used in developing countries, future adaptation benefits in the medium term and beyond are extremely small in current terms. Using a highly illustrative example and conventional discount rates for LDCs (e.g. 12%), the future stream of adaptation benefits (a few decades away) need to be many times greater than upfront adaptation costs, to pass an economic cost-benefit analysis. Analysis of the adaptation economics literature shows this level of benefits will be rare, especially given future benefits may not be realised due to uncertainty. In practical terms, this means that the limited resources available in such countries will most be better off spent elsewhere (i.e. to give more immediate social benefits) and it gives much greater preference to no-regret adaptation options as these produce immediate economic benefits. However, there are some cases where medium to long-term investments could be justified, and the study has examined these with some simple examples/schematics. They include:

- Where the costs of low cost overdesign (or flexibility or robustness) are extremely low;
- Where the costs of climate change and the benefits of adaptation are extremely high (when there are major shocks or indirect effects, such as from failure of critical infrastructure);
- When there are early benefits associated with longer-term adaptation options;
- When there is a value of information (though this is much lower than in the OECD context);
- Where there are future non-marginal effects.

Capital investments
While some capital investments today might appear vulnerable to future climate or to otherwise affect vulnerability to climate change, the resulting capital stock may depreciate so fast that its economic lifetime is relatively short. This has been reviewed, and found that capital depreciates faster in developing countries. However, even though depreciation in the African context is significantly faster than in the US, this suggests that decisions on assets taken over the

next few years will determine the character of capital stock for the next couple of decades, at least.

Quantitative assessment of decisions that lock in climate vulnerability

The study has analysed the potential infrastructure investment in future years in Africa. Looking across the indicators of infrastructure intensity as a whole, Nigeria appears to have the highest absolute investment needs in Sub-Saharan Africa – indeed, it has the highest needs for nine of the twelve indicators examined by a significant margin. Ethiopia and the DRC also score highly on a wide range of indicators. In all three cases, the key driver of this is the large size of the country both in terms of population and land area. Such effects become more pronounced when considering forecasts of these variables such as city population growth.

However, these same countries typically perform poorly when looking at the enabling environment for infrastructure investment. Composite credit ratings are roughly around the midpoint of Sub-Saharan Africa indicating each country has poor access to finance from international sources while the level of domestic credit available is within the lowest quartile suggesting resources available domestically are even scarcer. These countries also have an average WGI score between 20 and 30 per cent which may mean that even with favourable investment conditions, public institutions may fail to organise and implement such investments. Overall, it seems that Nigeria, Ethiopia and the DRC are likely to experience some investment in long-lived infrastructure in the medium term, particularly concerning urban planning, housing and amenities however, there are unlikely to be the leaders of Sub-Saharan Africa that the main analysis suggests.

Two particular intensity indicators that provided a different perspective were the share of irrigable land equipped for irrigation and hydropower production relative to potential. Within both, only a small subset of countries is likely to experience any significant investment in the future. While the DRC still has the highest investment needs for irrigation and Ethiopia for hydropower, other countries such as Angola, Mozambique and Zambia also required a substantial amount. These three countries scored moderately on both the investment climate indicators and the quality of governance indicator suggesting that a moderate level of investment in infrastructure in these sectors is likely.

South Africa had relatively high investment needs for both educational and social protection infrastructure. Similar to the effects of Nigeria's large population, this was caused primarily by South Africa's relatively high GDP which caused even a modest intensity gap to translate to substantial absolute investment needs. South Africa also scored relatively highly in both the access to finance indicators and the average WGI score suggesting that if there was sufficient demand, the opportunity for investments is available. Overall, this indicates that significant investment is likely to occur in infrastructure to provide both education and social and labour protection in the future.

TASK 2: PRACTICAL EXAMPLES OF LONG-TERM DECISIONS

This task has explored a number of evidence lines.

First, the study has reviewed the evidence base on the costs and benefits of adaptation in Africa. This has expanded considerably in recent years, due to a large number of global and country level initiatives on the economics of adaptation, and also sectoral studies that apply existing options to new contexts or locations. However, the majority of these use scenario-based impact assessment, and are thus of limited practical for real medium to long-term adaptation decision making.

Second, the study has briefly reviewed the methods and application of new decision support tools for adaptation, many of which are targeted to addressing uncertainty in medium to long-term decisions. There are now a number of studies using iterative risk management, real options analysis and robust decision making, though there are only a handful of such studies in Africa. However, these new methods for decision-making are resource-intensive and complex to use. Whilst they have potential application for major development initiatives and investments, they have limited application for more routine application (or in mainstreaming) in Africa: the priority is therefore to develop pragmatic, light-touch, approaches that capture the core concepts of these new methods and maintain a degree of economic rigour.

TASK 3 BARRIERS TO LONG-TERM DECISIONS

Barriers or constraints to adaptation are factors that make it harder to plan and implement adaptation actions. Barriers will make adaptation less efficient or less effective. Alternatively, it may require changes that lead to missed opportunities or higher costs.

The study has reviewed the literature on barriers to adaptation. It has also undertaken a further more detailed review in relation to behavioral economics. Finally, it is has drawn up an initial table of how the barriers might affect the medium to long-term adaptation decisions identified in previous sections.

Review of the literature

The main barriers to socially efficient adaptation are market failures, policy failures, governance failures and behavioral barriers.

Market failures can occur e.g. due to lack of information, the presence of externalities and public goods, information asymmetry and misaligned incentives. Economic theory applied to adaptation, as well as empirical observations, indicate that such actions will not receive appropriate levels of private investment. For example, under different market structures (monopoly, oligopoly or perfect competition), the ability of investors to reap the benefits of adaptation will vary, and therefore also their incentives to invest in it.

Policy failures occur when conflicting policy objectives co-exist (which is often) and there are not appropriate mechanisms for addressing these trade-offs, and when the current structure of institutions and regulatory policies is poorly aligned to account for adaptation objectives. For example, urban development objectives may not take into account the vulnerability of assets and human systems to climatic stresses. Also, when policies result in market distortions (e.g. price or income subsidies), people will under- or over-adapt depending on how their adaptation choices will translate into income changes.

Governance failures refer to ineffective institutional decision-making processes. Adaptation typically requires multiple actors and institutions with different objectives, jurisdictional

authority and levels of power and resources. The complexities of governance networks can indeed constrain adaptation. Overlapping mandates of government entities tend to create conflicts and slow adaptive responses. Further, lengthy bureaucratic processes and lack of transparency are an impediment to fiscal planning and access to finance, particularly relevant for developing countries. Poor - or lack of - leadership, lack of a clear mandate, and the short-term political cycle can also represent barriers to effective decision-making. Corruption within institutions also undermines adaptation efforts.

Behavioural barriers are concerned with the observed inability of individuals to take what appear to be rational decisions (i.e. to maximize their net benefits or utilities) and with their cognitive limitation in attempting to achieve their goals. This limitation manifests itself as inertia, procrastination, and the use of time-inconsistent discounting. Social values and beliefs can also support or hamper adaptation, in so far as they frame how societies develop rules and institutions to govern risk, and to manage social change and the allocation of scarce resources.

Further, individuals, institutions and the natural environment will clearly adapt within the boundaries of their adaptive capacity, and physical and biological constraints. Gender, age, education, access to infrastructure and finance, and access to markets and technology are all elements that determine the adaptive capacity of social systems. Natural systems' ability to adapt will be possible within certain climatic thresholds, and can be hampered by other non-climatic stresses, and the presence of physical barriers (e.g. the lack of corridors for species migration).

Mapping of barriers to decisions

The sections above highlight the potential barriers to adaptation. However, this provides a theoretical perspective. A key issue for the current study is to translate this into a more practical setting, and then look at potential solutions. To advance this analysis, the study has mapped the potential barriers identified above to the priority areas we have identified for medium to long-term adaptation decisions – focusing on spatial planning, service and infrastructure delivery - and proposes some possible solutions.

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INTRODUCTION

The UK's Department for International Development (DFID) and the Natural Environment Research Council (NERC) are jointly funding a five-year international research programme called Future Climate For Africa (FCFA). The programme aims to advance scientific understanding of sub-Saharan African climate on decadal timescales and promote better communication, use and uptake of climate information into long-term climate-resilient development strategies. To help inform the FCFA programme, a number of research projects have been commissioned, including this project on '*The Economics, Political Economy and Behavioural Science of Accounting for Long-term Climate in Decision Making Today*'. The study is being undertaken by the Global Climate Adaptation Partnership (GCAP), working with Vivid Economics, the UK Met Office and Atkins.

The project aims to analyse and identify the types of development decisions that should be actively accounting for future (10 years+) climate in decisions taken today, and will review the political economy and other barriers to achieving this. The main objective is to provide quantitative evidence on adaptation strategies that will help to inform decisions made by development practitioners in Africa. The findings of the project will feed into the FCFA research consortia and CCKE Unit to help inform their applied research and decision support services to various stakeholders. Specifically the project aims to:

- Develop and apply a simple framework that identifies where real policies, programmes and investments are being made today that have long-term implications for the vulnerability of local people or economies in Africa and where it would be rational to account for future climate in decision making today.
- Identify examples in Africa of where such long-term policies, programmes and investments are being made that have or have not successfully considered future climate in their implementation.
- Review the literature on the potential barriers to such a rational approach in practice, with particular focus on the political economy and behavioural barriers.
- For a small set of relevant (illustrative) cases, provide quantitative evidence on the economic rationale for adapting (or not) such decisions to cope with future (i.e. 10 years+) climate and where relevant, strategies for implementing adaptation, including the appropriate timing and sequencing of measures.

The project is broken into two phases. Phase 1 includes the following tasks:

a) Initial literature review on long-lived policies;

b) Identification of practical examples of long-term decisions;

c) Literature review on the barriers to long-term decision-making;

d) Development of initial conclusions and development of a framework and methodology for phase 2, which will undertake new case study analysis of the economics of long-term policies, plans or investments, to explore where it would be rational to account for future climate in decision making today

The report sets out the review findings for each of these four tasks in turn.

TASK 1: IDENTIFICATION OF LONG-LIVED POLICIES AND INVESTMENTS

The aim of this task is to review the academic and grey literature assessing where and how long-lived polices, plans and investments are being made across sub-Saharan Africa and where these will shape vulnerability, with focus on economic and similarly quantitative literature. To advance this a number of evidence lines have been investigated. These are:

- To review the literature to identify long-lived policies, plans and investments that are potentially vulnerable to medium to long-term climate change.
- To review those areas of development (from a national to local public development planning perspective) to identify areas of relevance and entry points.
- To investigate the economic case for medium to long-term climate interventions.
- To assess future capital investments and priorities for adaptation in Africa.

Literature Review

This task has reviewed the literature to identify potential lived policies, plans and investments.

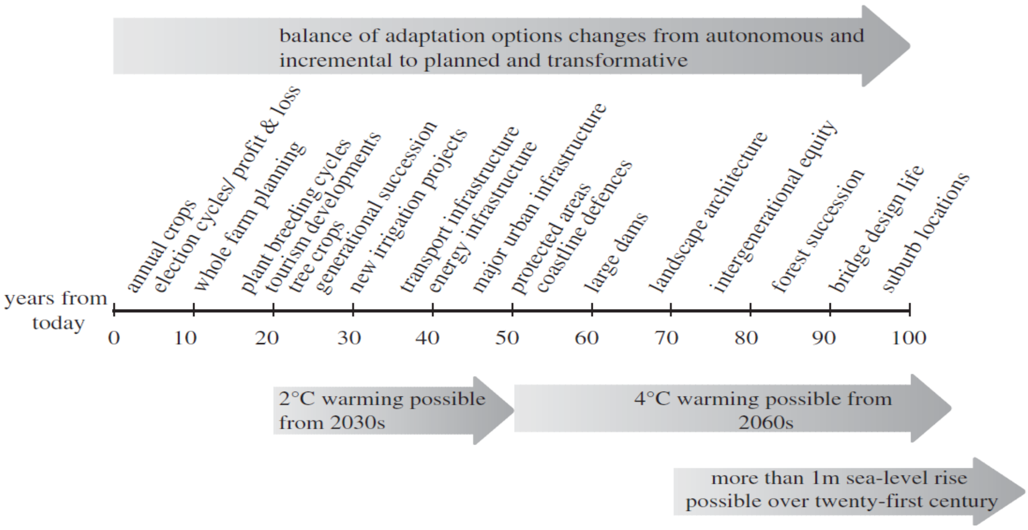
Future Priority Areas

There is a literature that examines types of investments that might be at risk from future climate change, based on lifetimes. Hallegatte (2009) identified a list of sectors in which climate change should already be taken into account, because of their investment time scales and their exposure to climate conditions, shown below.

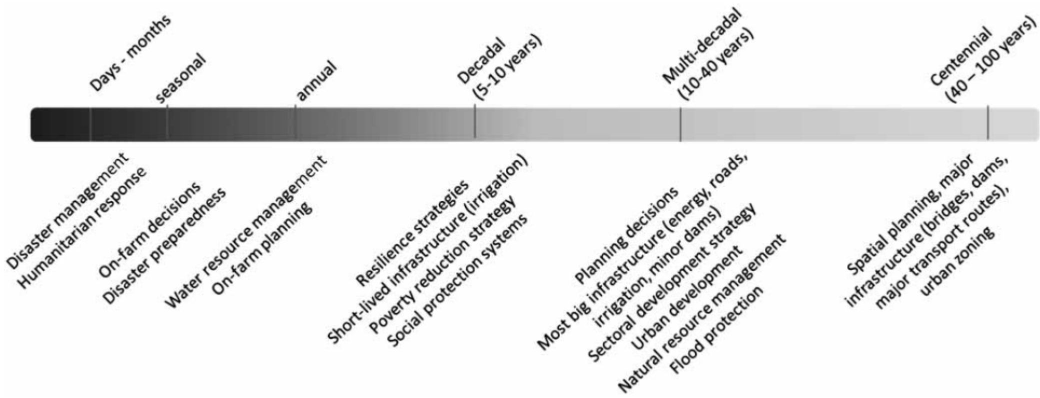
Sector	Time scale (year)	Exposure
Water infrastructures (e.g., dams, reservoirs)	30–200	+++
Land-use planning (e.g., in flood plain or coastal areas)	>100	+++
Coastline and flood defences (e.g., dikes, sea walls)	>50	+++
Building and housing (e.g., insulation, windows)	30–150	++
Transportation infrastructure (e.g., port, bridges)	30–200	+
Urbanism (e.g., urban density, parks)	>100	+
Energy production (e.g., nuclear plant cooling system)	20–70	+

Source :Hallegate (2009).

Stafford-Smith et al. 2011 present a similar concept graphically.



Ranger et al. (2014), updating Stafford-Smith et al. 2011, outlined the timescales of different types of climate-sensitive decisions, as below. Applying to a world bank portfolio for 250 projects, they report that between 2% and 30% of these may require action now to "future-proof" investments and policies.



Source: Ranger et al. (2014), updating Stafford-Smith et al. 2011

These studies both indicate a potential focus on infrastructure (notably water, irrigation and flood protection infrastructure, but also energy and transport infrastructure) and planning (especially urban and coastal planning), in the 5 to 40 year period of interest for the study. Additional areas of the built environment (Hallegatte) and natural resource management (Ranger) are also included. While social protection is assigned a decadal time-frame, the terms of reference highlight this is a potential area of interest, so this is also included.

This finding was generally borne out in the FCFA pilot studies (notably in Rwanda, but also in Maputo), which identified infrastructure and planning as key priority areas. However, the Rwanda pilot (Watkiss et al., 2014) also highlighted a more nuanced picture. As examples:

- While large hydropower investment was considered a priority for climate risk screening, the payback periods for small hydro did not justify action for investors. This was because companies were borrowing from Bank of Rwanda at interest rates of 18%, or from the FONERWA climate fund at 11%, and thus there was no financial incentive to increase up

front design costs for future risks (noting this might not be optimal from a societal point of view, especially when schemes are designed to transfer to government in the longer-term.

- For the road sector, there was a case of mal-adaptation identified for an actual policy. This involved a commitment to climate-proof rural feeder roads in the agricultural development strategy. This involves a cost penalty, which reduces the budget available, i.e. it leads to building a smaller number of higher quality roads, than working with current design standards. The key issue here is that the pavement lifetime of roads is around a decade, i.e. they will not be exposed to long-term climate change, thus this investment is a potential waste of resource. The study noted that siting roads to avoid current high risk areas is sensible, to avoid lock-in to climate risks (e.g. floods), and it will be cost-effective to ensure some degree of current resilience, allow some flexibility for later upgrades, or to focus on critical nodes with long life-times (bridges).
- In the water sector, the long-term integrated water resources plan, which extends out to 2040, had not considered climate change. This is a potential omission, especially given future irrigation plans. However, the role of climate change (and the level of uncertainty) in influencing future water demand was small compared to socio-economic development, i.e. climate is unlikely to be the main driver for the sector. Furthermore, as most climate projections indicated a small increase in water availability, the perception of climate risk was low (though the CMIP5 projections indicate a different outcome, which means this assumption was misleading).

At the same time, the FCFA pilots identified some areas not covered in the Hallegate and Ranger studies, including:

- Forestry management (commercial and management of natural and semi-natural areas). Commercial forestry uses a long-term financial model. This means it has similar attributes to infrastructure, in that there are risks of future climate change, but these are even more pronounced because returns on investment arise in the longer-term when trees are harvested. Forests are also climate sensitive (Ravindranath, 2007: Dasgupta et al, 2014: Settele et al., 2014), and maybe affected by changing trends over future decades (e.g. from changes in growth or quality, from incidence of pest and disease, or from damage associated with variability including wind). This leads to dual factors in relation to the planting of varieties (today) that will be suitable for the future bio-climatic zone under climate change (or more accurately a changing climate over time) as well as measures that reduce risks associated with variability. These issues also apply to REDD+ initiatives. Similar issues arise for conservation and management of natural and semi-natural forests, where there may be a need for early planning of buffer zones (land management) or active conservation options (e.g. translocation).
- Export crop development. Agriculture is usually an important contributor to export value in African countries, often associated with climate sensitive crops such as coffee and tea (e.g. in Ethiopia, coffee is around 75% of export commodity value and it is a major part of the future growth plans of the country). These crops have longer life-cycles than cereal crops (taking five to ten years for plantations to establish and become productive), and they also have long planning cycles (e.g. the time to switch coffee varieties, from early R&D, testing, roll-out, maturation and harvesting is over 20 years). Studies indicate that future bio-climatic shifts could make areas unsuitable for coffee (Davies et al., 2012) and thus early adaptation is important (as identified in the Ethiopian Climate Resilient Strategy, Watkiss et al., 2013). In many countries, such as Rwanda, there are plans to increase the areas of land

under cultivation for tea or coffee, which also involves early land-use planning decisions that will lock-in rural development patterns. There may also be similar issues for other crops, e.g. chocolate in West Africa, or viniculture in South Africa.

- Ecosystem services and limits. Natural and semi-natural ecosystems – and the services they provide – tend to be highly climate sensitive and have low adaptive capacity. Climate change will shift geographic ranges, seasonal activities, migration patterns, abundances, and species interactions, and has the potential to increase the rate of species extinction in the second half of the 21st century (Settele et al., 2014). These include major effects that could affect the provision of ecosystem services, which currently underpin many economies in Africa. While there are low regret options built around existing conservation and protection, this is also an area where more substantial adaptation maybe needed. There is the potential for early action from a precautionary perspective where there are very large risks (either high annual level, exceedance of thresholds, or large-scale or irreversible major effects) and/or where a lack of short-term action could lock in this future (systemic) damage to these systems. As a minimum, early monitoring and R&D is essential.

Frameworks

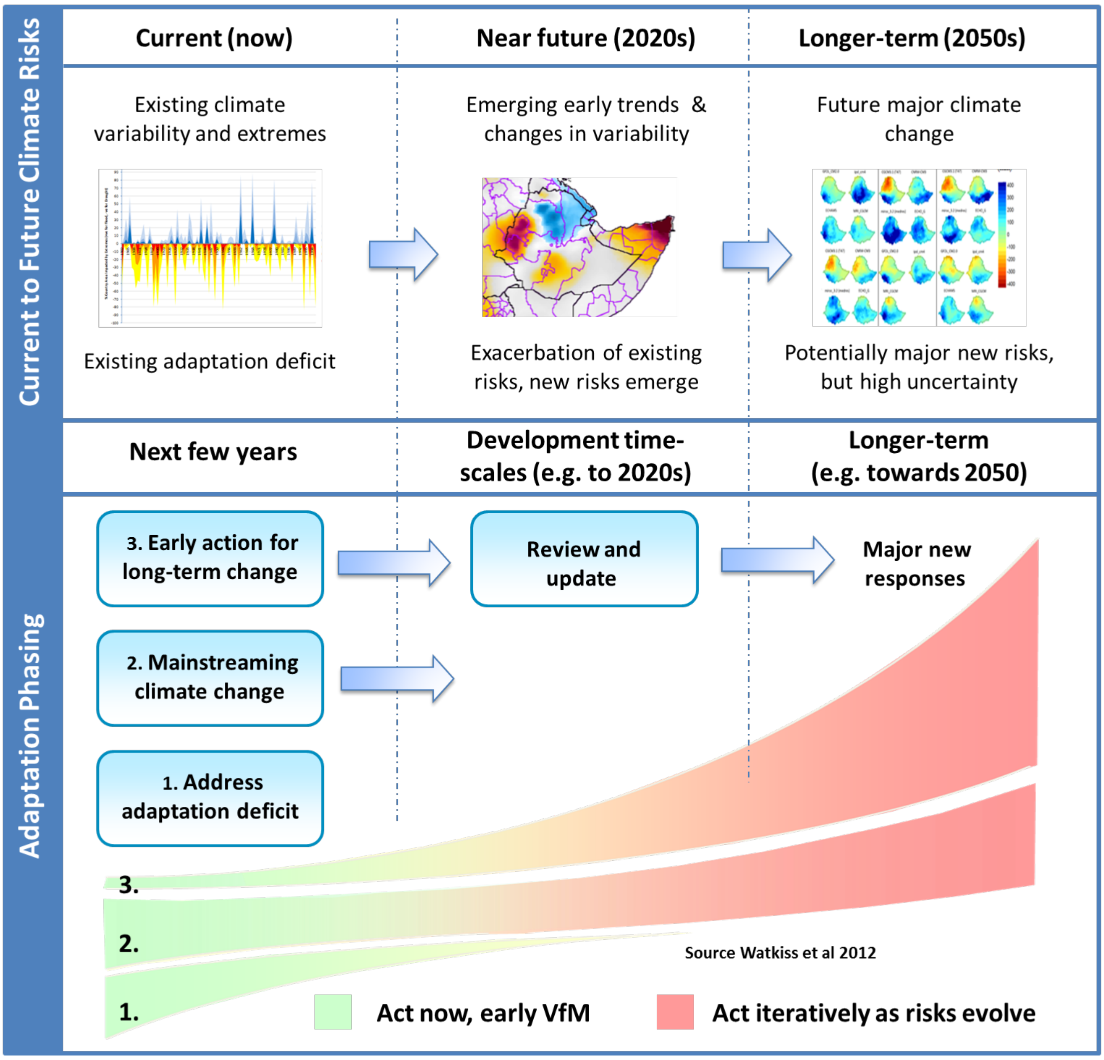
While the information above provides some general information on potential areas of focus, it is also necessary to look at the justification for early decision making for medium to long-term decision making, and to identify types of adaptation decisions.

Earlier studies considered the potential for longer-term decision making by using typologies of adaptation, often presenting these as building blocks or a spectrum of options (McGray et al., 2007; Klein and Persson, 2008). These included differentiated activities including addressing current vulnerability, building adaptive capacity, mainstreaming climate risks, and preparing for and tackling longer-term challenges – the latter two being of particular relevance for this study.

However, with the greater recognition of the uncertainty challenges of adaptation (e.g. UNFCCC, 2009; Hallegatte, 2009; Wilby and Dessai, 2010: World Bank, 2012), there has been a shift in the literature, away from policy-first impact assessment to iterative climate risk management, as seen in recent IPCCC reviews in the SREX and 5th Assessment Report (IPCC, 2012: IPCC, 2014). As a result, more recent updates of typologies of adaptation have made them more decision-led. They have also aligned the types of activities and decisions to iterative decision making frameworks (e.g. Ranger et al., 2010; Watkiss and Hunt, 2011; DFID, 2014). Importantly this recognises that each activity (or building block) is a different problem type, requiring different information, and varying methods of economic appraisal (Li, Mullan and Helgeson, 2015).

An example of such a typology is included in Box 1. The evolution of climate change is presented at the top of the figure, as a process that starts with current climate variability and evolves over time with increasing uncertainty. In response, the bottom of the figure outlines three different types of adaptation response, which address economic and uncertainty challenges. All three types need to be considered together in an integrated adaptation strategy, and the use of an adaptation pathway approach can capture and link the different activities together over time (Watkiss, 2012: Downing, 2012). For this study, the priority area of interest is for type 2 and 3 adaptation, i.e. where there is a stronger future climate component.

Box 1: Iterative Adaptive Management.
The figure below highlights the potential types of medium to long-term adaptation decisions, set within a framework of iterative climate risk management.



Source: Watkiss et al, 2014 (DFID, 2014), updated from Watkiss and Hunt, 2011.

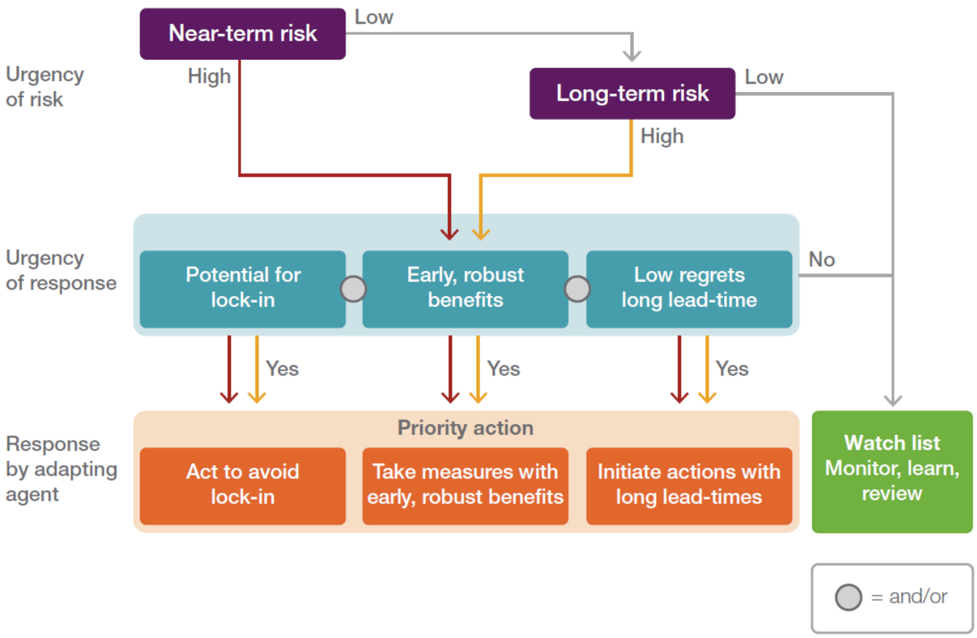
First, it prioritises early actions to address the current adaptation deficit and help to build resilience for the future. This involves early capacity-building and the introduction of low- and no-regret actions, which lead to immediate economic benefits. Such actions are grounded in current policy and can often use existing decision support tools. However, they are of less relevance for this study.

Second, there is early action to integrate adaptation into current decisions or activities with long life-times, such as infrastructure or planning. This requires alternative information sources and methods to above, because of the need to consider future climate change uncertainty. It also recognises that there is a need to consider options in a different way to normal appraisal, such as considering low-cost options, flexibility or robustness to address future uncertainty.

Finally, there is a need to consider the potential major impacts of climate change, noting the possible long time-scales and high uncertainty. The consideration of these longer-term issues involves important challenges and usually requires new approaches or thinking built around adaptive management. This entails learning from early activities, the identification of iterative portfolios that can be brought forward or delayed according to how the future develops, and early actions to address irreversibility, lock-in and encourage transformation.

Other similar frameworks exist. Fankhauser et al. (2013) outlines areas for early adaptation as:

- Adaptations with early, robust benefits. Fast-tracking adaptation makes sense if the proposed measures have immediate, robust benefits that would otherwise be forgone, for example, where there is an existing vulnerability or there are expected near-term impacts from climate change.
- 'Low-regrets' adaptation measures with long lead times. It makes sense to fast-track 'low-regrets' adaptations that have long lead times, such as research and development, even if the benefits will not accrue until later.
- Areas where decisions today could 'lock-in' vulnerability profiles for a long time. Fast-tracking adaptation is desirable if a wrong decision today makes us more vulnerable in the future and if those effects are costly to reverse. Several strategic decisions potentially fall into this category, including those on long-term infrastructure (e.g. the location of new airports, rail links and wind farms), land-use planning and the management of development trends, such as regional water demand. This includes:
    - Land management and long-lived investment and location decisions concerning buildings and infrastructure will have long-lasting effects on societal vulnerability to climate. These decisions can be difficult and costly to reverse or retrofit later.
    - A failure to manage other drivers of stresses, such as growing demand for water, rising and unstable food prices, environmental degradation and increasing prevalence of disease, could also lock-in future vulnerability to climate change. Tackling these issues now can strengthen long-term resilience and adaptive capacity



Illustrative decision-making process for prioritising adaptation

Source: Fankhauser et al., 2010.

It also highlights:

- Including safety margins for measures and policies today to cope with a wider range of possible climate conditions.
- Designing measures and policies today that can be easily and inexpensively adjusted later to cope with future climate conditions.

- Designing strategies that use a package of adaptation measures that are sequenced over time to reduce current climate risk, while maintaining flexibility to cope with future risks.
- Reducing the lifetime of decisions.

The DFID Topic Guidance (Ranger, 2013) takes this further and examines these concepts in the development context, identifying generic areas for development, shown below.

Generic classes of priority adaptation measures (Fankhauser et al. 2013), with specific applications to development interventions (based on OECD 2009 and Ranger and Garbett-Shiels, 2012).

Generic Area of Priority Action Source: Fankhauser *et al.* 2013	**Application to priorities for development interventions** Sources: OECD(2009) and Ranger and Garbett-Shiels, 2012
• ***Adaptations with early, robust benefits.*** Fast-tracking adaptation makes sense if the proposed measures have immediate, robust benefits that would be otherwise be forgone; for example, where there is an existing vulnerability or expected near-term impacts from climate change [low-regrets, see Section III.1]	• ***Invest in climate-resilient development.*** Well-designed development policies can be a no-regret form of adaptation through reducing social and economic vulnerability. • ***Reduce vulnerability to current climate variability and extreme weather events.*** Disaster risk management can be a low-regret adaptation, bringing immediate benefits. • ***Improve the availability and quality of climate information.*** Including monitoring systems, future scenarios and vulnerability assessments. • ***Adopt measures to reduce the immediate impacts of climate change and other stresses on the most vulnerable people and systems.*** Some human and natural systems, including terrestrial, marine and freshwater ecosystems, can be vulnerable to even small changes in climate. Actions could include enhancing the implementation of relevant multilateral and regional environmental agreement. • ***Review and adjust regulations and standards to reflect climate change impacts.*** For example, to help to remove any barriers to adaptation or perverse incentives (overcome market failures) on firms or individuals (Box X)
• ***Areas where decisions today could 'lock-in' vulnerability profiles for a long time.*** Fast-tracking adaptation is desirable if today's decisions could commit society to a particular more vulnerable development path that	• ***Incorporate climate change and adaptation considerations within national development policies,*** including long-term visions, poverty reduction, economic growth and sustainable development strategies. Avoid making decisions today in ways that could lock-in impacts or increase future vulnerability, instead seek low-cost ways to design strategies

would be costly to reverse later. Several strategic decisions fall into this category, including long-term infrastructure, land-use planning and managing development trends such as growing water demand.	so that they enhance long-term resilience. • ***Where dealing with expensive, long-term projects, such as public infrastructure or urban planning, seek options and strategies that will build in flexibility to cope with the uncertainty over future climate.*** This is relevant to new projects, but also upgrades and maintenance cycles.
• ***Building adaptive capacity***	• ***Building the long-term capacity for climate-resilient development,*** including developing appropriate institutional structures, skills and knowledge at multiple levels
• ***'Low-regret' adaptation measures with long lead times.*** It makes sense to fast-track low-regret adaptations that have long lead times, such as research and development, even if the benefits will not be accrued until later.	• ***Supporting the development and deployment of relevant agricultural technologies and other innovation*** that can reduce long-term social and economic vulnerabilities.

Ranger et al. (2014) identified three areas where additional action today is justified to adapt to future risks:

1. Long-lived, investments with large sunk costs, such as hydropower stations, roads, dams, and other infrastructure. A failure to account for climate change upfront in such long-lived investments could mean that they underperform (e.g., in the case of water supply systems and hydropower) or become exposed to increasing damage. This could mean that investments need to be retrofitted or replaced prematurely, imposing greater costs. For example, the lifetime of different investments; new transport and energy infrastructure can last for 40 years or more, large dams for at least 60 years, and patterns of urban development (the layout of suburbs, roads, and other infrastructure in a city), for more than 100 years. The climate is likely to be very different on these timescales. Capital investments are particularly prone to maladaptation because they tend to be difficult to change.

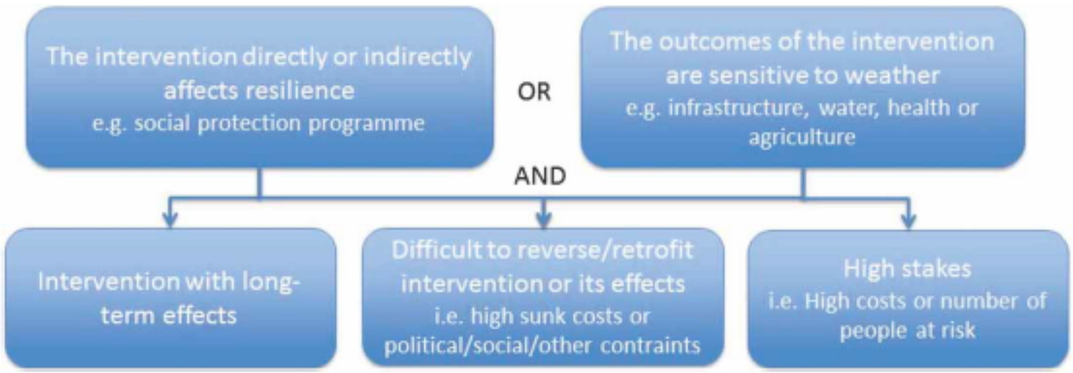
2. Long-term planning and policy-making, such as growth strategies, sector development plans, a poverty reduction strategy, coastal development plans, drought contingency plans, and urban zoning can have far-reaching and complex consequences that influence vulnerability for decades. In some cases, they will have positive co-benefits for long-term resilience, for example, through strengthening governance, building capacity, and increasing access to credit. But in a few cases there is a risk of maladaptation when people are inadvertently committed to greater and difficult-to-reverse decisions that may increase the risk from climate change. This includes:

- Social protection systems can increase resilience to climate shocks but will need to be adjusted over time to cope with the changing profile of vulnerability and climate risks If this adaptability is not built in from the start, systems can be difficult to adjust over time, due to political, social, or legislative barriers, making them less effective.
- A programme that promoted water-intensive agriculture may change behaviour semi-irreversibly and be detrimental if the climate became drier.
- A rural roads programme that built intersections on floodplains could lead to urban development and put these communities at risk in the long term.
- A project that built schools on a floodplain could, at best, limit access to education for local children, or at worst, put them in danger.
- Even short-lived projects, like climate-smart agriculture or rural development programmes, can cumulatively add-up to major changes in long-term resilience in unexpected ways.

3. Interventions with long lead-times: in cases where measures will take many years to implement, it may need to start now. For example:

- Removing barriers to adaptation and building adaptive capacity can take time, as it can involve major changes in institutional, governance, and legislative structures (e.g., land and water rights), decision processes, and cultural norms and behaviour.
- Research and development, for example, to develop and pilot new agricultural technologies can also take many years.
- Changing livelihoods and migration, for example, enabling rural communities in unsustainable areas to move and seek new economic opportunities can take time.

Ranger et al. (2014) presented a decision tree to help development practitioners screen where a development intervention is likely to require some adaptation today to account for future (10 years+) climate. This is shown below. This leads to a set of criteria that can help in identifying projects where it may be beneficial to future-proof now. In general, where the project or its outcomes are long-lived (i.e., long-term), difficult-to-adjust, and have a high cost or impact (i.e., high stakes) then climate change is likely to be a central factor in design today. This framework is illustrated by the lower three blocks.



Simple framework illustrating the conditions under which long-term climate change is likely to be an important factor in the design of a programme

Source: Ranger et al. 2014

A final matrix, from Dercon 2014, identifies where interventions are likely to be high value for money today (in green) and where interventions will likely require some adaptation to reduce the risk of lock-in (in red).

Environmental programmes through a poverty and irreversibility lens

		Fighting poverty NOW in poor countries	
		Low benefit in next few years	**High benefit in next few years (high value for money, low-regret measures)**
Risk of LOCK-IN in poor countries (IRREVER-SIBILITY)	**Low Risk of Lock-In**	AGRICULTURE Long-term climate proofing of smallholder agriculture INFRASTRUCTURE High-cost hazard proofing of schools and health centres to cope with long term climate	DISASTER PREPAREDNESS Investing in improved early warning systems and emergency planning AGRICULTURE Enhancing productivity and resilience of agriculture to current climate variability WATER, SANITATION, HYGIENE Drinking water and sanitation Solid waste management
	High Risk of Lock-In	ENVIRONMENT/AGRICULTURE: Deforestation Coastal zone/natural areas protection Fisheries management	CITIES/INFRASTRUCTURE Urban master planning: waste management, urban transport, urban land use, urban infrastructure WATER, SANITATION, HYGIENE Large scale water resources AGRICULTURE/FOOD Environmentally sensitive land use/ intensification in commercial agriculture

Source: Based upon Dercon (2014) with modications

Review of Development Planning (Public Policy)

The section above identifies types of lived policies, plans and investments, and a way to view potential early adaptation for medium to long-term decisions. However, it is also useful to identify the types of processes that are involved with these decisions, as these are critical in looking at practical implementation of adaptation (IDRC, 2015)[1].

A key issue here relates to relevant entry points (OECD, 2009; UNDP-UNEP, 2012), i.e. the opportunities in the national, sector or project planning process where climate risk considerations can best be integrated. These are particularly important for adaptation, because there is a current focus on **mainstreaming**, which seeks to integrate adaptation into existing processes and decision-making across a range of policy areas, rather than introducing stand-alone adaptation policy. In this regard, adaptation is very different to mitigation (Watkiss, Benzie and Klein, 2015) and this is due to the strong overlap between adaptation and existing activities that address current climate resilience (e.g. disaster risk reduction, water management, etc.).

Policy measures that will affect adaptation are often implemented for non-climate reasons, with multiple objectives and ancillary costs and benefits that are material to the overall choice of the measures. It is therefore important to understand the context for an intervention and decision, including the existing policy and objectives, non-climatic drivers, and the current decision-making process. As an example, resilience may be mainstreamed as part of an urban regeneration programme, but the design of such a programme will be dominated by local

[1] This section summarises recent work undertaken by the project team as part of the IDRC funded project on the Economics of Climate Resilience, and will be published in the OECD book 'ECONOMICS OF ADAPTATION IN OECD COUNTRIES' in June 2015.

economic development objectives and other drivers, such as demographic and land-use change. Such a mainstreaming practice will also require a good understanding of the individual organisations, institutional networks and processes making relevant decisions. Critically, all of these will differ with each specific adaptation problem.

In the African context, this therefore requires an understanding of the links between climate change adaptation and national or sector development priorities. It is also important to consider how these linkages cascade from high level strategic policy through to implementation, as well as how they are situated within the institutional and political contexts.

Interesting, in a developing country context, mainstreaming activities usually follow a slightly different path than in developed countries, with different entry points, reflecting the differences in national strategic planning. In this context, there are a set of entry points for mainstreaming, outlined in the table below (UNDP-UNEP, 2011) noting that these often operate through different organisational leads. This structure closely parallels that outlined for environmental mainstreaming more generally (OECD, 2012).

Possible entry points for mainstreaming in national strategic planning policy in developing countries

Planning level	**Entry point**
National government and cross sector ministries	• National development vision (long-term) • Poverty reduction strategy • National development plan (e.g. 5 year) • National budget allocation process or review
Sector ministries	• Sector development plans • Sector master plans • Sector budgets
Subnational authorities	• Decentralisation plans • District plans • Subnational budgets

Source: UNDP/UNEP (2011), Mainstreaming Climate Change Adaptation into Development Planning: A Guide for Practitioners, UNDP-UNEP Poverty-Environment Initiative, Kenya

This situation is made slightly more complicated as many developing countries are producing National Adaptation Plans (NAP). The UN guidance for the development of NAPs outlines the need for mainstreaming in developing such plans - critical because of the strong overlap with existing development activities (LDC Expert Group, 2012a; 2012b), however, most existing initiatives tend to be undertaken as stand-alone activities.

There are now examples of the practical implementation of mainstreaming in some African countries, though countries have adopted a range of approaches.

One route – or modality – is to introduce adaptation as an extension to existing environmental mainstreaming. For example, some countries already include “environment” as a cross-cutting theme in their national development vision, national development plans (e.g. medium-term plans, five year plans or poverty reduction strategies), and sector development plans. An example is the Government of Rwanda, which has integrated climate change (with

environment) as one of seven cross-cutting issues in national development and sector development planning (Republic of Rwanda, 2014). It is even possible to extend this to capture climate mainstreaming, and in Rwanda, these activities are being integrated, or at least tracked, in the national budget allocation process and in sector budget activities.

Other countries have adopted a slightly different approach, developing stand-alone sectoral adaptation action, plans which complement existing sector development plans and activities. Examples include Ethiopia, with its Climate Resilience Strategy for Agriculture (FDRE, 2014) and Tanzania, which has developed a sector Agriculture Climate Resilience Plan, 2014–2019 (GoT, 2014). These mainstreaming initiatives are led by the relevant sector ministries/line-ministries and build on existing sector development plans, but produce stand-alone and costed adaptation plans, because of the differentiation/opportunity for climate finance. This approach is clearly influenced by the potential for additional international climate finance, though it involves less direct integration.

Moving down to the programme and project level, existing safeguard mechanisms, such as environmental impact assessment (EIA), provide a natural entry-point for considering whether projects are vulnerable to climate change or could exacerbate climate risks elsewhere. Although originally designed to prevent negative impacts on the environment, the EIA process has the benefit of being a familiar and well-established part of the policy-making process in OECD countries. However, it only captures those policies that are subject to environmental impact assessments, such as infrastructure construction. Moreover, it may require revision of the legal framework to include climate risks. As discussed later, it may also come too late in the process to be really influential.

More generally, climate risk screening can be applied as a step in the policy-making process to identify where policies, programmes or projects may be particularly vulnerable to climate change. This has emerged strongly in relation to investment projects funded by the international finance institutions and multilateral development banks. For example, the African Development Bank (AfDB, 2011) has introduced a Climate Safeguard System that includes a traffic light system or scorecard to identify which projects may be highly vulnerable to climate risk and require a more detailed evaluation to consider integration of climate aspects into design and implementation. These tend to have a strong focus on enhancing the climate resilience of infrastructure or major investments. This does raise an interesting point in that the stimulus for medium-long term decisions may come from the development community and from stipulations on finance, which is likely to be more influential than when originating from sectors in LDCs themselves.

A complement to the identification of high-risk policies, projects and programmes is the integration of adaptation into existing policy and project appraisal guidance. This entails the modification of existing appraisal guidance to also cover climate change or to support the consideration of some of the additional aspects and challenges of adaptation. However, such guidance is often weak in sub-Saharan countries.

Finally, a further approach is to update climate change allowances, as has been done for floods in several OECD countries (Wilby and Keenan, 2012): this can be extended to update design standards. However, caution is needed to ensure that the benefits of such actions justify the additional costs, especially given future discounting of uncertain benefits

In looking at these issues, recent studies have highlighted that mainstreaming environment or climate change does involve major challenges, notably due to the lack of capacity, time and resources in the sectors (i.e. as climate decisions move from the Ministry of Environment outwards).

These studies also provide some useful recommendations on how to address these challenges.

The OECD (2012) study on greening development highlighted specific interventions including: using multi-year development planning processes, develop key actors technical skills, encourage the participation of non-government actors, build functional and technical skills, and plan and target efforts carefully. It also provided some recommendations on how development support can deliver better capacity, highlighting: view capacity support for the environment as underpinning all development support, collaborate across domestic agencies, harmonise approaches among development support providers, nurture local ownership, focus on results, implement best practice guidelines, and reflect and learn.

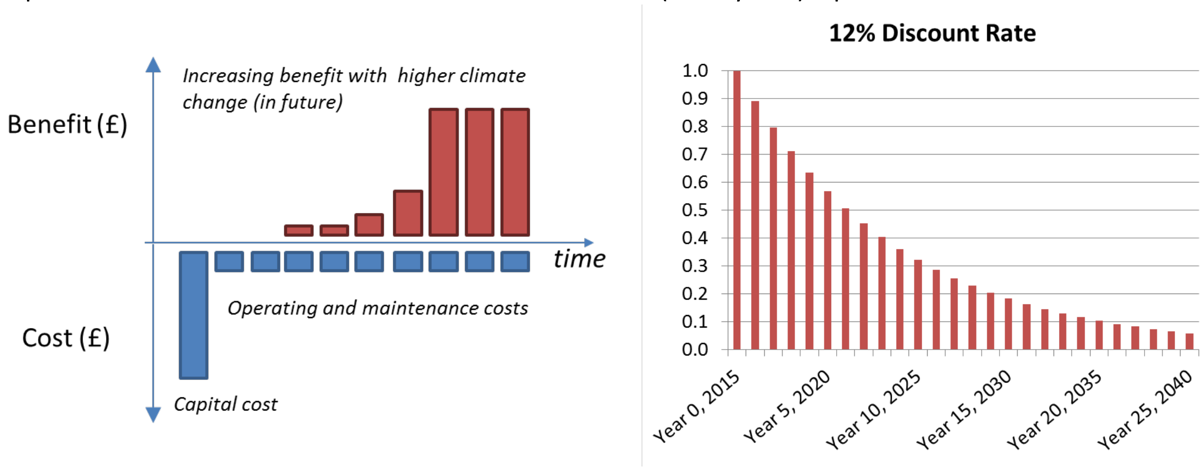
The IDRC (OECD, 2015) review highlights:

- Mainstreaming will need to align to the policy and institutional landscape, and consider existing processes or guidance, such as project cycle steps and appraisal documentation already in place.
- Pragmatism is essential as any tool or guidance need to fit with the resource, time, capacity and expertise available for policy or project analysts; otherwise they will not get used.
- The stage at the decision-making process when adaptation is considered is critical. It is important to ensure that the mainstreaming activities come early enough in the process to influence the decision, or are targeted at key 'windows of opportunity' (Ballard, 2014; Moser and Ekstrom, 2010) which will often be non-climatic in nature (e.g. replacement or maintenance cycles). This may require strategic issues to be picked up early-on, either in relation to the sector strategy or the overall investment portfolio (e.g. at river basin level rather than project level). It also means that climate risks and mainstreaming activities needs to occur early in the project cycle, at the concept or design stage, and ideally be aligned to approval milestones. The inclusion of adaptation considerations at the environmental impact assessment stage, for example, is usually too late to have a major influence on project design.
- It may be useful for decision-makers to also identify opportunities that can be created by implementing adaptation, rather than focusing only on the risks and amelioration actions (Hallegatte, 2011).
- The path from identifying potential entry points and providing tools through to implementation is challenging. Achieving this requires involving a diversity of users and stakeholders, finding relevant champions, building partnerships and providing support networks and capacity building.

The Economic Case for Action (or Not)

While the sections above provide some generic priority areas, it is important to look at the economic case for action to test these assumptions. This is particularly important for medium and long-term decision making, because of the profile of costs and benefits over time for adaptation decisions (DFID, 2014).

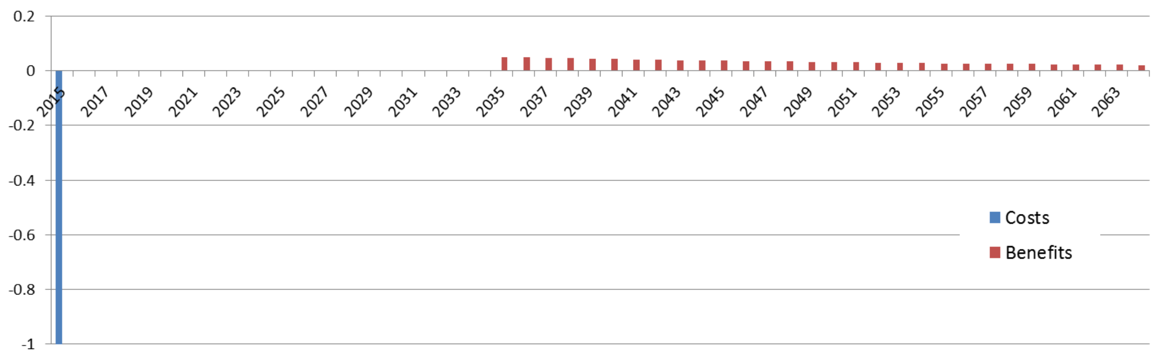
In many cases, the most important impacts of climate change are likely to arise in the future, say 2030 and beyond, when the climate signal emerges. Within economic analysis, the benefits of adapting to these changes accumulate over longer, future time horizons, while the costs are incurred now. Using the public discount rates conventionally used in developing countries (e.g. DFID usually works with a 12% discount rate – though further discussion on this is presented later), future adaptation benefits in the medium term and beyond are very small in current terms. This can be seen in the figure below. A £1 benefit that arises in 2040 (in 25 years), has a present value of £0.06 and even a £1 benefit in 2030 (in 15 years) a present value of £0.18.



Profile of costs and benefits for medium-long-term adaptation (left) and effect of discounting (right) showing the value of a future benefit (in years from 2014 to 2040) when discounted back to a current present value

Source: FCFA, 2014: DFID, 2014

To show how dramatic the effect of discounting really is, particularly in developing countries, a simple example is provided below. We start with an upfront adaptation cost of £1 in year 0, and compare this to a stream of future adaptation benefits. These adaptation benefits start in 2035 (in 20 years), and deliver a benefit of £0.1/year, continuing at this level over the next 30 years. The total undiscounted benefits are therefore £3 (compared to the up-front cost of £1). However, these future benefits need to be discounted: using conventional UK declining discount rates (starting at 3.5%), the discounted stream of benefits is approximately £1, thus the costs and benefits are broadly equal (i.e. the benefit:cost ratio is approx. 1). This high decline happens because the discount rates I time-invariant, implying exponential reductions.



Profile of costs and benefits for medium-long-term adaptation, comparing £1 in 2015 (adaptation costs) with a total stream of adaptation benefits of £3 (2035 – 2065), which after discounting at 3.5% declining also equal ~£1 in present value terms (approx. BCR = 1).

However, if this same example is considered in the developing country context, using a typical discount rate of 12%, the picture changes dramatically. In fact the annual benefit stream of £3 (undiscounted), drops by an order of magnitude, to approximately £0.1, thus the benefit:cost ratio is ~0.1, which is highly unattractive.

The corollary of this is that to get a benefit:cost ratio of approximately 1 in a developing country, the annual benefit stream has to increase by an order of magnitude, i.e. an upfront adaptation cost of £1 only makes economic sense if the annual stream of benefits are £1/year, starting in 2035 and extending continually for 30 years. Incredibly, this means that a total adaptation benefit of £30, after discounting at 12%, equates to only approximately £1 in present value terms.

Analysis of the ECONADAPT inventory (on adaptation costs and benefits) shows that this level of benefits to costs is fairly unprecedented. There are some examples of undiscounted benefit to cost ratios that are this high for early DRR options, and for long-term coastal protection, but these are exceptions.

In practical terms, this means that the limited resources available in such countries are better off spent elsewhere (i.e. to give higher social benefit) and gives greater preference to low- and no-regret options as these produce immediate economic benefits.

However, there may be some cases where medium to long-term investments can be justified, and the study has examined these with some simple examples/schematics. They are outlined below and draw on some of the low-regret, value-for-money analysis identified in the DFID study (2014) for mainstreaming and addressing long-term challenges.

The costs of resilience are very low

Early studies (see Agrawala and Fankhauser: OECD, 2008) estimated the costs of adaptation using an investment and financial flow analysis method. This applies an adaptation cost "mark-up" to future investment plans to take account of future climate change, usually around 10% (for example, the World Bank (2006) estimated that accounting for future climate in high-risk projects today could potentially increase project costs by between 5% and 15%). In practical terms, this means that if adaptation increases the costs of a project by 10%, then the benefits

that it produces need to be greater than 100% and occur in each year, if they start in the future, at least for a 12% discount rate (see above).

However, if the costs of adaptation are very low, then there may still be a justification for early action. For example, if the costs of adaptation are 1% of the project costs (or £0.1 in the schematic above), and deliver future benefits (£0.1 per year, totalling £3 undiscounted, and just under £1 discounted, thus approximately a BCR of ~1), then the investment may make sense. Of course, the actual ratio of project costs and future benefits will vary on a case by case basis, but this illustrates that if very low cost over-design is possible, then this might be worth considering, even under conditions of high discount rates (though perhaps not under conditions of high future uncertainty).

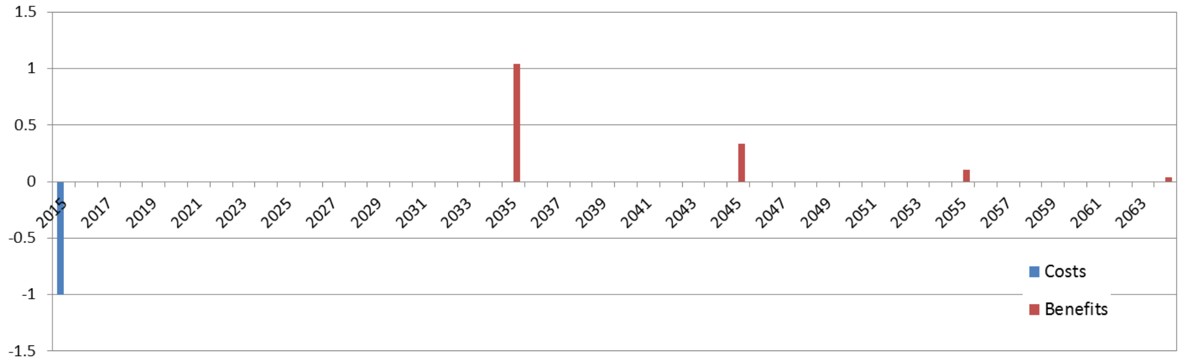
The future impacts of climate change are very high (shocks and indirect effects)

Reversing the logic above, there will also be a case for adaptation when the future adaptation benefits are very high. This may arise for a number of reasons.

First, when the impacts of climate change, and thus the potential benefits of adaptation in terms of avoided damages, are very large. This may arise from large shocks (natural hazards). Major extremes, such as major floods, tropical storms, or major droughts, already lead to high economic costs (IPCC, 2012), and changes in the frequency and intensity of major events could lead to large future damage costs. In turn, the benefits of disaster risk reduction could be very large.

If there is an existing high adaptation deficit, noting these events are probabilistic in nature, early action will have benefits in reducing the risks of early damage. However, this is a low-regret option, i.e. this is something that should be done anyway and therefore not directly relevant to the 10 – 40 year lifetime of interest. The issue therefore is whether the change in risks associated with climate change should be accounted for in early DRR actions, i.e. whether coastal or river flood dikes should be built higher to take account of changes in storm-surge or flood intensity. It is therefore the marginal costs – and the marginal benefits – to address future risks, which is important here (noting this gets very complicated very quickly, because it depends on the assumptions of return periods).

What is clear is that using the simplified schematic above, the marginal costs of these additional events (or their extra intensity) needs to be very large to justify additional early costs. The figure below assumes that a large event occurs every ten years, starting in 20 years. If this leads to large damage costs – and by association large adaptation benefits (shown as an adaptation benefit of £10 every ten year, discounted at 12%) – then this passes a CBA test. However, what is interesting is that it is only the first event that justifies the early costs (this alone has a benefit to cost ratio of 1): whereas very large future events get discounted very heavily (as can be seen by the declining present value of future events). As above, adaptation may reduce but not eliminate the effects of these events, and these events are probabilistic as well as uncertain, so they may not materialise.



Profile of costs and benefits for long-term adaptation, investigating future shock and high future adaptation benefits.

A second case arises when there are indirect effects. Using floods as an example, this would include direct effects (e.g. building damage), direct intangible impacts (e.g. loss of life, damage to ecosystems), indirect effects (disruption to transport or electricity) and indirect intangible effects (e.g. effects on well-being from post disaster stress). This has clear overlap with the extremes above, but of most relevance, it could apply critical infrastructure.

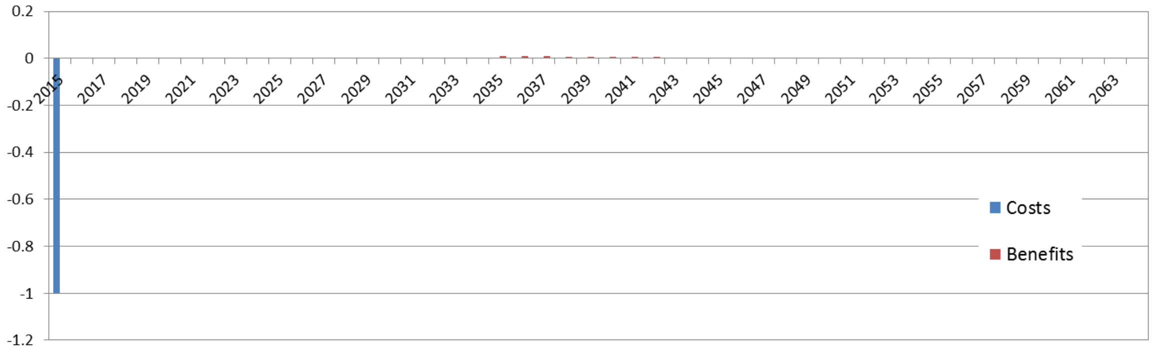
Infrastructure is deemed critical if its failure threatens the safety, economy, lifestyle and public health of a city, a region, or even a state. These critical infrastructures are specific in that they go beyond geographical, political, cultural and organisational boundaries (Boin & McConnell, 2007). The World Bank (2011) has highlighted previously that critical infrastructure is a priority for future proofing. If during an event, critical infrastructure is destroyed (e.g. water supply systems, water treatment, healthcare infrastructure, etc.), this will lead to larger indirect effects including intangible effects. For this reason, there is likely to be a stronger economic case for over-protecting critical infrastructure, in economic as well as social and health terms.

Future benefits start now and build up over time

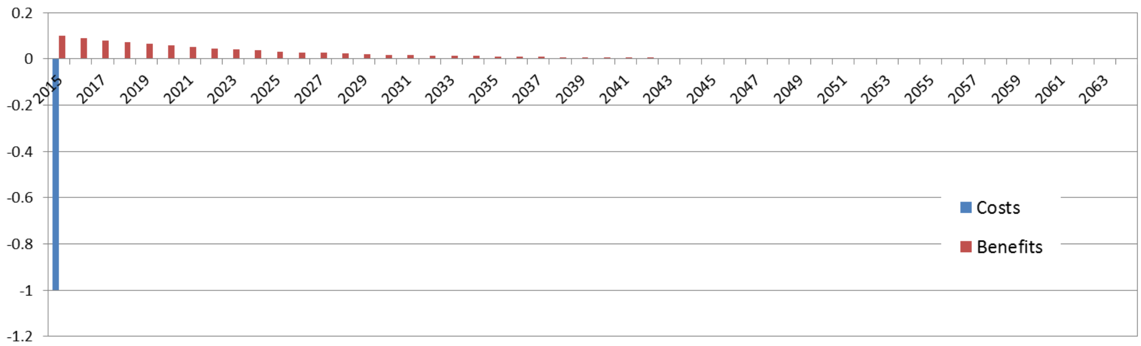
A further case where early action might be justified is when there are some early benefits of early adaptation action, even if these are not sufficient to justify investment on their own. Two figures are shown below to illustrate this. The first assumes an adaptation cost of £1 in year 0. It then compares this to a benefit stream starting in 2035 of £0.1/year, continuing for 30 years (£3). After discounting at 12%, the stream of future benefits only totals ~£0.1, thus fails a cost-benefit analysis (BCR ~0.1).

However, if early benefits are factored in, things improve significantly. If we assume adaptation benefits start in year 1, at £0.1/year, and continue at this level over time, then the present value of benefits increases to just under £1 after discounting (at 12%), thus an approximate BCR of ~1.

This does run into some problems, notably there need to be early robust climate trends which can generate these benefits, and it is a fine line as to whether most of these options will be early low-regret measures. Furthermore, the delivery of benefits in the first few years is critical, as these provide the largest discounted benefits.



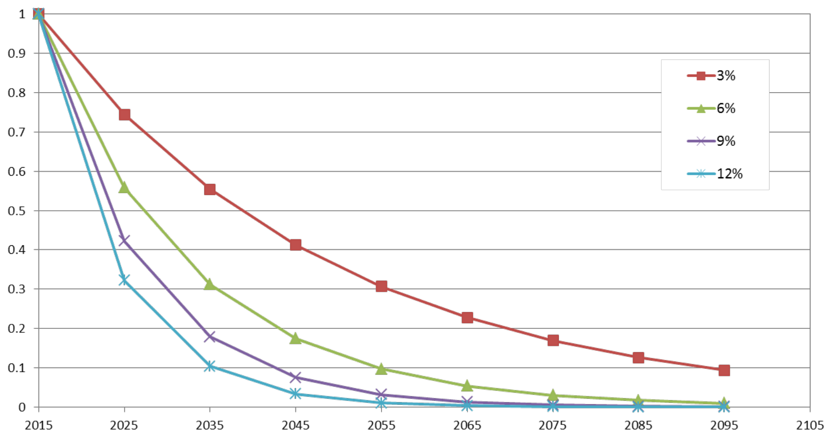
Profile of costs and benefits for medium-long-term adaptation, comparing £1 in 2015 (adaptation costs) with a total stream of adaptation benefits of £3 (2035 – 2065), which after discounting at 12% declining equals approx.. £1 in present value terms (BCR = ~0.1).



Profile of costs and benefits for adaptation, comparing £1 in 2015 (adaptation costs) with a total stream of adaptation benefits of £5 (2015 – 2065), which after discounting at 12% declining equals approx.. £1 in present value terms (BCR = 1).

Different assumptions are made on discount rates

Clearly one of the simplest ways to increase the attractiveness of long-term adaptation is to change the assumptions – provided this can be justified. As can be seen from the first example, the discount rate needs to drop significantly to make a difference for long-term benefits, i.e. towards the rates used in OECD countries. However, given the extremely high impact of discounting at 12%, even modest reductions in discount rate can make a large difference – the figure below shows the impact of reducing rates.



Discounting in UK Public Policy Appraisal

HMT (2007) recommends a Social Time Preference Rate (STPR) for public policy appraisal, derived from the equation $\rho + \mu.g$, based on the Ramsey discounting formula, where:

ρ = the rate at which individuals discount future consumption over present consumption, which is combined with

- the product of the annual growth in per capita consumption (g) and
- the elasticity of marginal utility of consumption (μ) with respect to utility, *reflecting the fact that if per capita consumption is expected to grow over time, this will imply future consumption will be plentiful relative to the current position and thus have lower marginal utility.*

ρ itself comprises of two elements:

- Catastrophe risk (L); and
- Pure time preference (δ).

Catastrophe risk is the likelihood that there will be some event so devastating that all returns from policies, programmes or projects are eliminated, or at least radically and unpredictably altered. Examples are technological advancements that lead to premature obsolescence, or natural disasters, major wars. The pure time preference, reflects individuals' preference for consumption now, rather than later, with an unchanging level of consumption per capita over time.

HMT (2007) reports that the evidence indicates a value for ρ of around 1.5 per cent a year for the near future, an annual rate of g at 2 per cent per year, and an elasticity of the marginal utility of consumption (μ) of around 1. Therefore with g = 2 per cent, ρ = 1.5 per cent, μ = 1.0, then the real discount rate is 0.015 +1.0*0.02 = 3.5 per cent.

Why use 10-12% in developing countries?

In theory, a similar UK social discount formula can be applied in developing countries, though clearly ρ is much higher (because they are poorer and because growth rates and future incomes are higher). This leads to higher discount rates than used in the OECD (noting OECD rates are typically 3 to 6%).

However, the convention is to use social discount rates of 10-12% in developing countries, which implies rates that are higher than would arise from the use of the Ramsey formula above. In practice, these rates are based on alternative approaches for deriving the social discount rate. A good review of practice is included in the ADB review of Zhuang et al., 2007).

In summary, as well as the use of the Ramsey formula, Zhuang also cites examples of the empirical estimation of SRTP. They also report on the use of the Marginal Social Opportunity Cost of Capital for estimating social discount rates. This argues that resources in any economy are scarce, that government and private sector compete for the same pool of funds; that public investment displaces private investment, and thus that public investment should yield at least the same return as private investment. A further alternative is to use a weighted average approach, to reconcile the SRTP approach with that of SOC, and a further variation of this, using the shadow price of capital (SPC).

Zhuang et al., 2007 also summarise discount rates in use, noting that various countries use STRP or SOC approaches (the latter generally leading to higher rates). In general, the review found more use of STRP in developed countries and more use of SOC in developing countries (e.g. India and Pakistan use 12% (SOC)), though with some use of weighed averages in MDBs.

However, a more practical review, focused on development partners and international/multi-lateral finance organizations, as part of this study, reveals that rates are often not based on a strong economic rationale.

The World Bank published a Handbook on Economic Evaluation of Investment Operations (Belli et al, 1997), on page 127, it says: "[...] The discount rate used should reflect not only the likely returns of funds in their best relevant alternative use (i.e., the opportunity cost of capital or "investment rate of interest"), but also the marginal rate at which savers are willing to save in the country (i.e., the rate at which the value of consumption falls over time, or "consumption rate of interest"). The Bank traditionally has not calculated a discount rate but has used 10-12 percent as a notional figure for evaluating Bank–financed projects. This notional figure is not necessarily the opportunity cost of capital in borrower countries, but is more properly viewed as a rationing device for World Bank funds. Task managers may use a different discount rate, as long as departures from the 10-12 percent rate have been justified in the Country Assistance Strategy.

The ADB follows the WB and adopts the same approach. ADB Guidelines states that because it is too difficult to precisely estimate the opportunity cost of capital in each country, 10-12% is used. see page 37 http://www.adb.org/sites/default/files/institutional-document/32256/eco-analysis-projects.pdf

Sources: HMT (2007); World Bank (2007), ADB [Zhuang et al] 2007.

There are some potential reasons why a lower discount rate might be used. Applying high discount rates to countries in the future may be biased, as their future growth will slow with development, and uncertainty and catastrophe risk will also fall. There is a discussion whether climate change itself might reduce future growth, which would imply the use of lower or declining discount rates for adaptation.

A further set of adjustments can be introduced, declining rates (HMT, 2003) [hyperbolic discounting] or intergenerational discount rates (HMT, 2009).

The declining rate (in the UK) is used because of uncertainty about the future values of time preference and calculates a certainty equivalent rate taking into account the range of this uncertainty. However, because the reduced rates do not kick-in until year 31, see the schedules below for the standard declining and intergenerational declining schemes, this will not make much difference to a developing country context that starts with a high discount rate (because the main effect of discounting will have already occurred). Of course in the UK or OECD context, where lower social discount rates are used, these schemes do make a difference.

The use of intergenerational rate reflects the fact that discounting can lead to perverse outcomes, especially where potential catastrophic consequences occur in the future, even if these can be avoided with small early investment (i.e. the end of the world becomes optimal). This is a particular issue for climate change mitigation. As highlighted by Weitzman (2009), with climate change, there is the potential for plausible, if unknown, catastrophic climate change and so called 'fat tails', where the tails of the distribution dominate and the expected welfare loss is potentially unbounded (e.g. due to mass species extinction and biosphere ecosystem disintegration). The consideration of these extreme outcomes leads to radically different conclusions from the conventional standard economic analysis and formalized cost benefit analysis.

There is a strong economic justification for avoiding these extreme outcomes (Stern et al, 2006) and the Stern review effectively used a 0.1% value of ρ in the Ramsey formula above, due to the catastrophic risk – leading to low rates, though it still discounted for growth.

HMT (2009) introduced a discounting scheme to take account of intergenerational issues, i.e. irreversible wealth transfers from the future to the present. This is different to the Stern scheme and is shown below.

Period of years	**0–30**	**31–75**	**76–125**	**126–200**	**201–300**	**301+**
Standard rate as published in the Green Book	3.50%	3.00%	2.50%	2.00%	1.50%	1.00%
Reduced rate where "Pure STP" = 0[1]	3.00%	2.57%	2.14%	1.71%	1.29%	0.86%

Source HMT, 2008.

Again, such an adjustment may not make as much difference in the LDC context, because this is a fairly low component of the overall social discount rate. In developing countries, the growth component of the discount rate is much higher, thus changes in ρ are less likely to impact on the final rate.

Option values and the value of information are included

Real options analysis (ROA) quantifies the investment risk with uncertain future outcomes. It is particularly useful when considering the value of flexibility with respect to the timing of capital investment, or adjustment of the size and nature of investment over a number of stages in response to unfolding events. In the adaptation context, this allows for the analysis of flexibility, learning and future information, particularly relevant for uncertainty (McDonald and Siegel, 1986; Dixit and Pindyck, 1994).

It is particularly useful when considering the value of flexibility with respect to the timing of capital investment, or adjustment of the size and nature of investment over a number of stages in response to unfolding events. In the adaptation context, this allows for the analysis of flexibility, learning and future information, particularly relevant for uncertainty (Watkiss et al, 2014). ROA typically gives two types of result that set it apart from conventional economic analysis.

The first applies to projects that are cost-efficient under a deterministic analysis: ROA may show that it makes more sense to wait for the outcome of new information, rather than investing immediately, if the benefits of the new information outweigh the costs – i.e. deferred benefits – of delaying implementation. The value of waiting will then be higher if the degree of uncertainty regarding the return of the project is greater; and the duration of the period of waiting before information is gained is shorter. The value of waiting needs to be balanced against the cost of waiting, because while waiting, the project will not be delivering benefits.

The second applies to projects which fail a conventional CBA under deterministic analysis, but under conditions of uncertainty it may make financial sense to start the initial stages, or at least

keep the option open for potential future investment. This arises because ROA helps understand how project value evolves during development: there will often be flexibility to adjust the project as it proceeds and it can expand, contract or stop. ROA can incorporate this value of flexibility (which is omitted in standard economic analysis). As with CBA, effective treatment of risk preferences depends on the ability of the analyst to describe these accurately.

However, as ROA depends on expected values within a conventional economic framework, the discounting issues in developing countries will still arise. Indeed, the penalty of waiting and deferring early project benefits in countries experiencing high GDP growth will be high.

Other (sustainability) arguments are introduced

A further set of literature highlights that while economics (and the use of discounting) reflects preferences, this can result in somewhat strange outcomes (e.g. as in the mitigation domain, where the 'end of the world' can become optimal).

A number of different arguments have therefore been advanced to highlight key problems, or to include extra criteria or adjustments that should be made to standard CBA.

As an example, Annandale (2013) presents a case on large hydropower sites in the context of a limited number of suitable sites. He highlights that these sites are affected by sedimentation, which reduces storage capacity. Current economic analysis does not take account of the costs of lost storage, because it is discounted heavily as it occurs in the future after many years. As a result, ongoing sedimentation management approaches do not appear favour. However, this then leads to high levels of siltation that render the sites unusable without major sedimentation removal. As a result, he raises the principle of hotelling, i.e. that the value of an exhaustible resource increases with the discount rate (i.e. discounted value does not change), though the economic case for this is not strong (indeed a better approach might be to use real options analysis, see above).

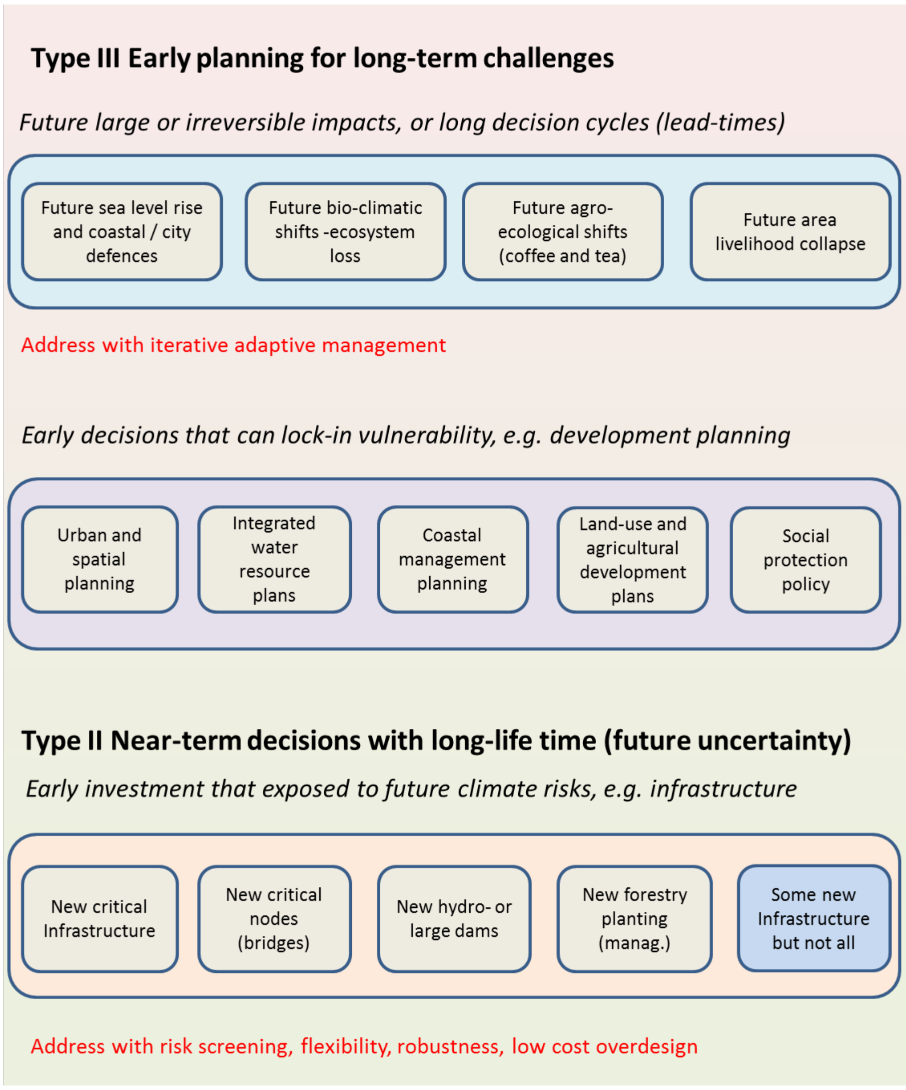
Discussion

Drawing on the sections above, the key areas identified for medium and long-term planning are outlined below, split into type II (short-term decisions with a long life-time) and type III (addressing future challenges).

The priorities include:

- Critical infrastructure, because of role post disaster (noting failure during major climate shocks will lead to high indirect losses). This could include bridges as critical nodes for similar reasons, and because of the largely irreversible nature.
- Large hydropower (or water storage), noting this is affected by changing trends because of the ongoing operational costs of lower generation or unmet demand in drier scenarios, as well as damage from heavy precipitation extremes.
- Urban land-use planning, due to the long life-time of spatial decisions, and the potential exposure to future extremes (and indirect costs).
- Agricultural land-use planning and development, especially coffee and tea, forestry management, due to the long life-times involved.
- Infrastructure – if there is opportunity for low cost over-design, flexibility or robustness.

- A number of major future major effects, where some early iterative planning is warranted because of irreversibility and high rates of change/low adaptive capacity.



These form possible areas to explore in the case studies in phase 2.

Capital Investments

What's the issue?

In putting together a conceptual framework for identifying decisions today that affect climate vulnerability in the long term and that should take future climatic conditions into account, it is important to be aware of rates of depreciation on the sorts of capital investment involved.

While some capital investments today might appear vulnerable to future climate or to otherwise affect vulnerability to climate change, the resulting capital stock may depreciate so fast that its economic lifetime is relatively short, say not more than a decade or two, wherein current climate variability is the dominant factor in its performance.

Capital depreciation in Africa

Capital depreciation is a relatively under-researched issue. In the vast majority of studies, the rate of depreciation is simply assumed and moreover the same rate is assumed to apply to different countries. Typical assumptions for the aggregate capital stock are in a range from about 7% (Easterly & Rebelo 1993) to about 10% (Nordhaus & Sztorc 2013), which implies that, over the course of its first decade in use, the value of a representative asset falls by 52-65% and after 20 years it does so by 67-88%.

However, there are reasons to believe that rates of capital depreciation are not uniform across countries and in particular that there may be systematic differences between countries based on their level of development. In theory, the disparity could go either way:

- Capital depreciation in lower-income countries such as those in Africa could be lower than in high-income countries, if a large proportion of investment is in used rather than new goods, used goods depreciating more slowly.
- On the other hand, it tends to be assumed that, if there is a difference, it is that capital in lower-income countries depreciates faster. There are several candidate explanations for this, including financial constraints that lead investors to purchase less durable investment goods (Udry et al. 2006), and in particular a range of mechanisms that ultimately result in under-maintenance of capital assets, including that the goods are imported from high-income countries and are unsuitable for local conditions, corruption (Davoodi & Tanzi 1997), anticipated capital under-utilisation (which makes it efficient to do less maintenance), high rates of time preference, and market distortions that makes capital investment artificially cheap.

There have been two recent studies estimating capital depreciation rates in developing countries, both focusing on the manufacturing sector.

Schuendeln (2013) analyses survey data for Indonesian firms and estimates depreciation rates between 8% for a simple statistical model and 14% for a model with more convincing controls. Larger and younger firms had higher depreciation rates, which may indicate they use newer equipment.

A more directly relevant study is Bu (2006), who analysed survey data from manufacturing firms in seven developing countries including four countries in Sub-Saharan Africa (Cote d'Ivoire, Ghana, Kenya and Zimbabwe). The data are rather noisy, so, using the median firm as the measure of central tendency, depreciation rates in the African countries varied from 17% to 62% across countries and using different methods of accounting for inflation. This study also looks at depreciation rates for different kinds of asset, finding that depreciation is lower for buildings and higher for machinery and equipment, as one might expect.

Overall, Bu concludes on the basis of the evidence that capital depreciates faster in developing countries and the evidence in Schuendeln might also be taken as (somewhat equivocal) support for this.

Useful life of fixed assets

In addition to studies on the depreciation rate of the capital stock in aggregate, research has examined the depreciation rates of individual asset classes. These studies, in turn, inform tax codes. Countries such as the US provide standard asset lives to be used in calculations of corporate tax liabilities for a wide variety of asset classes, many of which are relevant for this study.
Unfortunately, studies on the depreciation rates of particular asset classes in developing countries, and in Africa in particular, are rare. Tax codes tend to distinguish between many fewer classes of assets, if guidance on useful lives is provided at all. In addition, there is often no evidence that the judgements on useful lives provided within tax codes are based on rigorous research on the depreciation rate of assets.

Table 1 provides the useful life of fixed assets as estimated by the Bureau of Economic Analysis, based in the United States, and useful lives for equivalent assets as recommended by the IRS for use in calculating tax liabilities. For the BEA data, where possible, depreciation rates have been estimated using asset prices in the resale market. Where no direct data were available, the rates have been based on a variety of sources, including 'the research of BEA, Dale Jorgenson, the Bureau of Labor Statistics, and Jack Faucett Associates, as well as their own judgement to determine the geometric rate of depreciation on a case by case basis'. The methodology used by the IRS is less transparent, but a slightly broader range of assets appears to be covered. The useful lives reported in each of the two sources are broadly consistent.

As can be seen, most of the assets considered of relevance in this project appear to have useful lives between 30 and 50 years. Even if depreciation in the African context is significantly faster than in the US, this suggests that decisions on assets taken over the next few years will determine the character of capital stock for the next couple of decades, at least.

Depreciation rate and useful life of fixed assets, BEA

Sector	Asset type (BEA)	Useful life (years, BEA)	Asset type (IRS)	Useful life (years, IRS)
Energy and communications infrastructure	Communication structures	40	Telephone distribution plant	24
	Electrical transmission, distribution and industrial apparatus	33	Electric power generating and distributing systems	19
	Electric light and power structures	45	Electric utility steam production plant	28
			Electric utility hydraulic power plant	50
Urban planning, infrastructure and reconstruction	Sewage and waste disposal	40	Municipal wastewater treatment plant	24
			Municipal sewer	50
			Residential rental property	27.5
Water supply	Water supply	40	Water utilities	50
Transport infrastructure	Railroad equipment	28	Railroad structures	30
	Railroad replacement	38	Railroad track	10

Sector	Asset type (BEA)	Useful life (years, BEA)	Asset type (IRS)	Useful life (years, IRS)
	track			
	Air transportation structures	38		
	Highway and conservation and development structures	40		
Public buildings	Medical buildings	36	Non-residential real property	39
	Educational buildings	48		

Source: http://www.bea.gov/national/pdf/BEA_depreciation_rates.pdf, http://www.irs.gov/pub/irs-pdf/p946.pdf

Quantitative assessment of decisions that lock in climate vulnerability

Introduction and methods

Previous work has given us useful frameworks for identifying what kinds of decision, being made today, are likely to require consideration of future climate in their design and implementation. These are decisions that:

1. Affect climate vulnerability (either the performance of the project itself is vulnerable to climate, or project outcomes more broadly affect vulnerability to climate);
2. Do so in the long run (10 years or more);
3. Are quasi-irreversible;
4. Are large enough to merit attention from development organisations.

Ranger, Harvey and Garbett-Shiels (2014) analysed 250 development projects from the World Bank and DFID in three countries and identified the types of project most 'urgent' according to criteria similar to those above. In no particular order they are:[2]

- Energy and communications infrastructure;
- Urban planning, infrastructure and reconstruction;
- Water supply infrastructure;
- Transport infrastructure;
- Major hydropower;
- Major irrigation infrastructure;
- Public buildings (schools, hospitals);
- Natural resource management.

However, we lack a quantitative understanding of where these kinds of investment decisions are likely to be made in Sub-Saharan Africa in the coming years. Where are the hotspots, which would consequently be deserving of special attention?

[2] Weather-risk insurance and social safety net programmes are mentioned in this paper, though not included in the list.

This section seeks to identify potential hotspots for infrastructure investment that affects climate vulnerability and that requires consideration of future climate in design and implementation today. It does so using a series of quantitative indicators that are comparable on a national basis across the whole Sub-Saharan African region, obtained from a range of international databases.

It is not to be confused with quantitative analysis of climate vulnerability (e.g. Barr, Fankhauser, & Hamilton, 2010; Yohe et al., 2006). Such analysis is concerned not with decision-making and investment *per se*, but with the outcomes for climate vulnerability. Therefore the focus in these studies is on measures of exposure/impact such as damage to crop yields, measures of sensitivity such as food import dependency, and measures of adaptive capacity such as governance indices.

The principal methodological problem confronted in doing a regional, comparative analysis of infrastructure investment is that suitable, direct data do not in general exist. Therefore indirect proxies must be relied upon. For some of the above categories of infrastructure, good proxies do exist. For instance, projections can be obtained from UNDESA of population growth in cities in Sub-Saharan Africa, which is strongly indicative of likely future urban planning and infrastructure investment. Such data are included in this analysis.

Yet for the most part this is not the case and reliance must be placed on more indirect proxies. To this end we rely centrally on the notion of infrastructure deficits (Yepes et al., 2008) or *infrastructure intensity gaps*, in order to quantify the potential for future investment.

The justification for doing so lies in the empirically demonstrated phenomenon of convergence of economies along a growth path (e.g. Barro & Sala-i-Martin, 2004). Economies that start further behind gradually catch up with the leaders in terms not only of ultimate living standards, but also capital or infrastructure intensity: they grow faster on these dimensions. The implication is that those countries with a large gap relative to a leading, benchmark country in a suitably normalised measure of infrastructure (i.e. infrastructure intensity) have the potential to see most investment in the future.

The analysis that follows calculates and presents results for a range of measures of infrastructure intensity corresponding to the various categories of infrastructure affecting future climate vulnerability mentioned above. Intensity is calculated in different ways depending on the category of infrastructure. For example:

- The slum population may be normalised by the total urban population. Countries with the largest share of slum-dwellers have the greatest need of urban planning and infrastructure investment to provide adequate conditions for such people and the greatest potential according to the convergence story.
- The area of agricultural land that is equipped for irrigation may be normalised by the estimated area of total irrigable land to show where there is potential for investment in further irrigation.

The benchmark country that is chosen for the analysis is the developing country, anywhere in the world, with the highest infrastructure intensity in a particular category. An alternative would be to benchmark against the leading country in Sub-Saharan Africa, but, insofar as an absolute, cardinal interpretation can be given to the data, doing so would not convey the potential for

further investment even in the leading country. Regardless, a potential weakness is that the benchmark country may have unique characteristics, which make it especially infrastructure-intensive. We account for this where possible (for example, very small countries are excluded from benchmarking with respect to paved road density), but further work could be carried out to exclude outliers.

Each of our indicators is normalised by an underlying absolute variable to ensure that they are comparable across countries. To calculate what level of investment would be required to close an infrastructure intensity gap, the gap is multiplied by the current value of the underlying absolute variable to arrive at an absolute level of investment. For example, the in public spending on education as a percentage of GDP is multiplied by current GDP to arrive at the absolute additional level of spending required to close the gap.

For most of the indicators, forecasts of the underlying variable are then multiplied by the infrastructure intensity benchmark in order to estimate what investment would be required to maintain infrastructure intensity at the benchmark level. The latest available forecasts are used for each underlying variable. This is not possible for some underlying variables such as irrigable land or potential for hydropower production as they are constant over time or forecasts are unavailable.

Unless otherwise stated, the results presented in this analysis are the sum of the investment required to first, close the current infrastructure intensity gap and second, maintain the benchmark intensity in the future. This absolute level of investment is then standardised by the total range of investment needs for each indicator so that each country is assigned a value between 0 and 1.

Of course countries do not always neatly follow a process of convergence. The existence of an infrastructure-intensity gap does not automatically imply that the gap will be closed; it may exist for a good reason such as weak governance. To account for this, we present two further sets of results.

First, infrastructure intensity gaps can be calculated not with respect to the leading country in each category, but with respect to what each country might be expected to have achieved, given its level of development and other national characteristics. In particular, Yepes et al. (2008) carry out an econometric analysis of the determinants of various kinds of infrastructure intensity in developing countries, showing that they depend among other things on national income per capita and population density. We use the statistical estimates from this work to provide a prediction of what degree of infrastructure intensity a country would have, given the average effect of national characteristics such as income per capita on infrastructure intensity across all developing countries. If a gap exists, then it is not explained by these characteristics and it might be assumed to be more readily closed.

Second, data on infrastructure intensity gaps can be compared with data on governance and the national investment climate. If a large gap exists, yet the investment climate is poor, it can be concluded that it is less likely to be closed.

Results

For each of the indicators examined, the following section presents:

- A definition;
- An explanation of its relevance to investment in long-lived infrastructure; and
- Data on the investment required by each country in Sub-Saharan Africa to close its infrastructure intensity gap relative to the most infrastructure-intensive developing country.

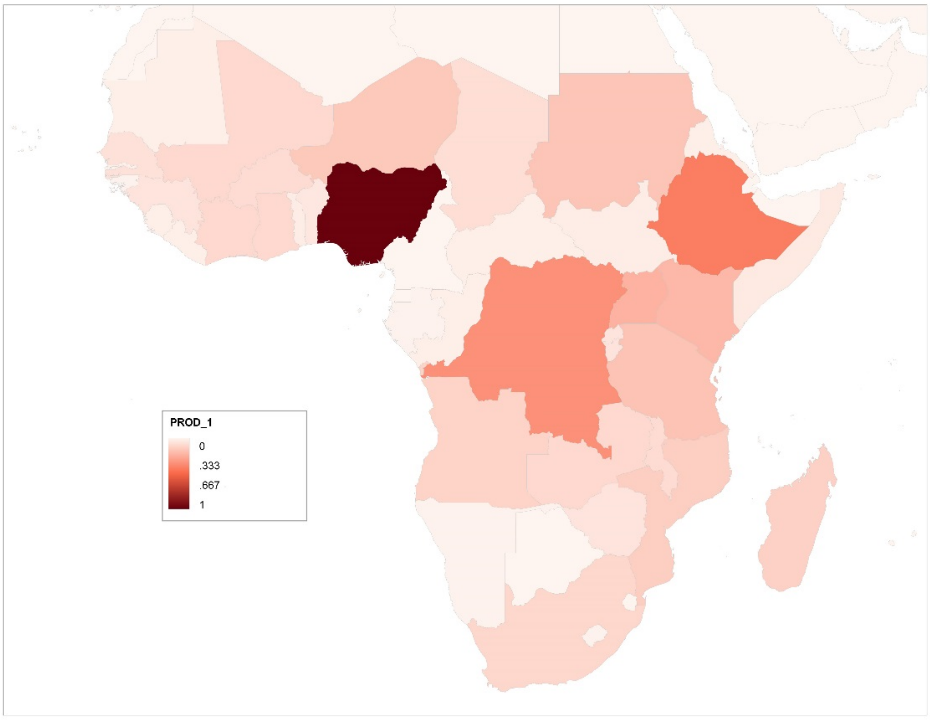
National indicators

Produced capital intensity

Produced capital intensity measures how intensively capital is used in an economy. It is defined as the value of the total stock of productive capital per capita where productive capital can be physical capital such as machinery, buildings and transport infrastructure as well as urban land. Higher levels of productive capital intensity are associated with increased labour productivity. As countries develop and economic activity shifts away from agriculture and towards manufacturing and services, produced capital intensity is likely to increase, which requires investment in a wide range of long lived assets.

As the figure demonstrates, Nigeria requires the most future investment, in absolute terms, in productive capital by a large margin, owing mainly to high rates of expected future population growth. Ethiopia and the Democratic Republic of the Congo (DRC), the second and third highest, require less than half of this investment. There is also a wide range of countries in the north and south east of Sub-Saharan Africa requiring between 10 and 20 per cent of Nigeria's investment needs.

<u>Nigeria requires more than double the additional productive capital of any other country</u>



Note: Countries for which data was unavailable appear as 0.
Source: World Bank (2013, 2014), Vivid Economics

Urban planning and infrastructure

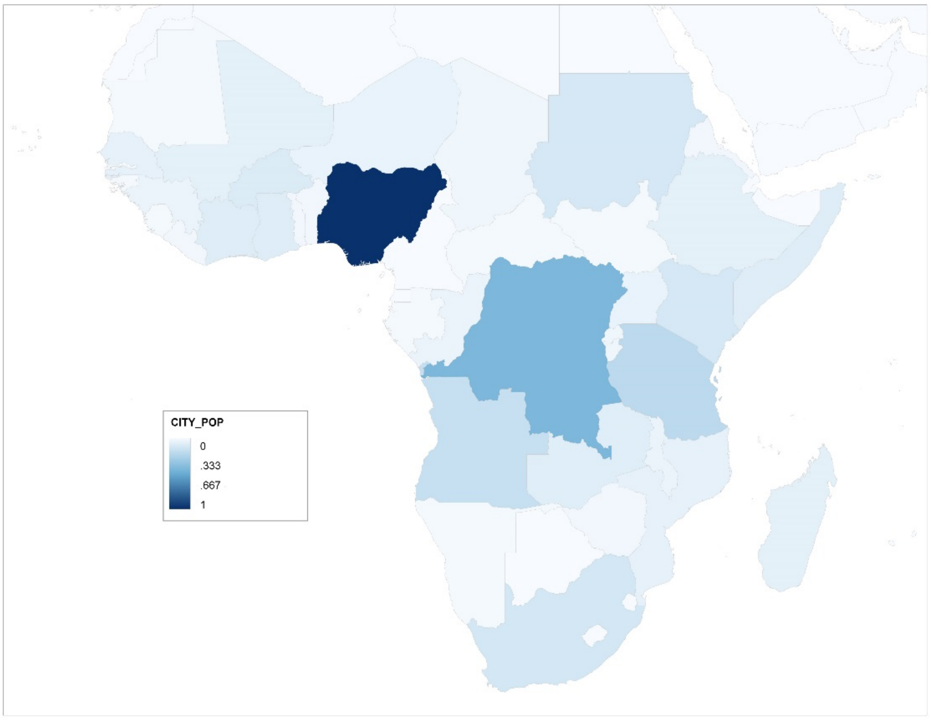
City population growth forecasts

To ensure basic living standards are met for any increase in the population of cities, the quantity of housing and the provision of amenities such as water, electricity and sanitation must be expanded. Urban planning regulations can often be complex and hence investment plans can take a long time to organise and approve. Moreover, data from the US suggests that supporting infrastructure such as water pipelines and sewerage systems can stay in place for up to 50 years (US Department of the Treasury, 2012). While asset lives in Sub-Saharan Africa may be shorter, urban infrastructure can cast a shadow on spatial patterns of development that lasts much longer than the life of the original asset (e.g. the street pattern in the City of London still bears the imprint of Roman settlement patterns).

National urban population growth is defined as the sum of population changes in all agglomerations in a given country that are over 300,000 people in size, and the forecasting horizon is up to 2030.

Nigeria experiences the vast majority of growth in the population of cities and hence will require the highest investment in urban planning and service provision, as reflected below. The DRC requires around 44 per cent of this investment and only five other countries require more than 10 per cent.

<u>City population growth is concentrated in Nigeria and the Democratic Republic of the Congo</u>



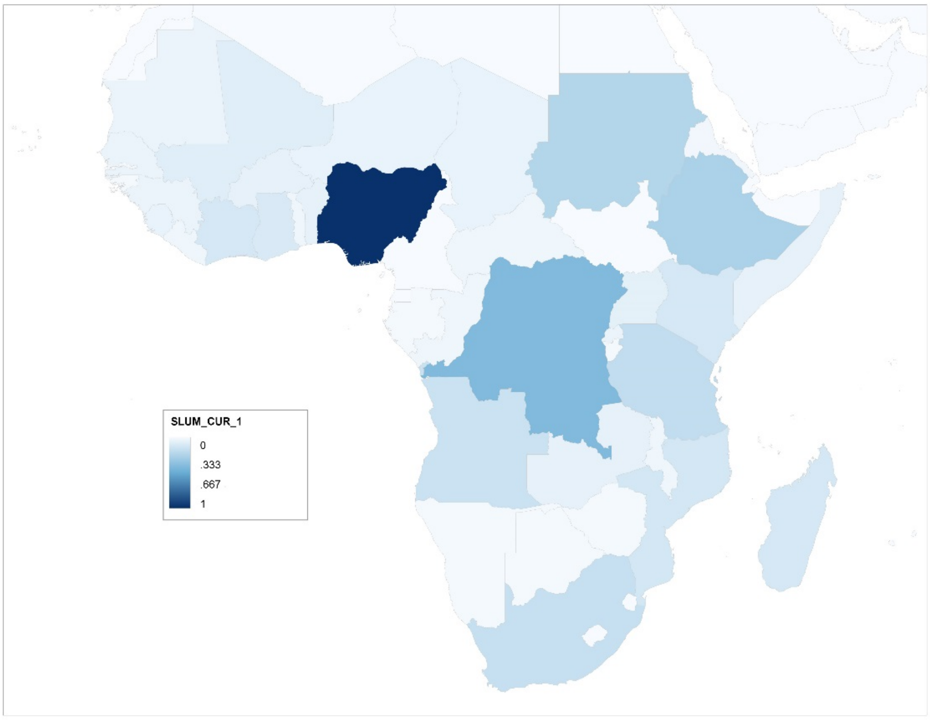
Note: Countries for which data was unavailable appear as 0.
Source: UNDESA (2014), Vivid Economics

Share of urban population living in slums

Slums typically have a high population density and lack access to electricity and water. As countries develop, the share of the urban population living in slums is likely to decrease as incomes rise and people seek better living conditions. Similar to city population growth, this will require substantial investments in long lived infrastructure to ensure basic amenities can be provided.

The figure presents the relative investment required to achieve the lowest share of the population living in slums across all developing countries, given each country's *current* population. It does not account for future growth in population. This shows a very similar pattern to that of city population growth, with Nigeria and the DRC requiring the most investment in infrastructure followed by several countries on the east coast.

The share of urban population living in slums tells a similar story to city population growth



Note: *Countries for which data was unavailable appear as 0.*
Source: *World Bank (2014b), Vivid Economics*

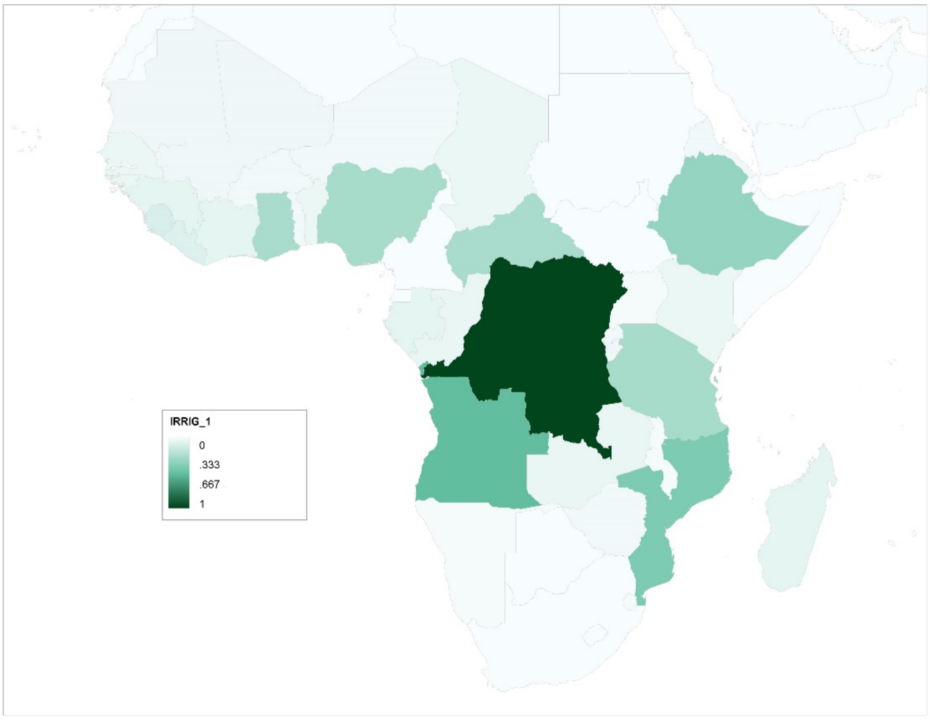
Irrigation infrastructure

Share of irrigable land equipped for irrigation

Irrigation can dramatically increase crop yields, the productivity of labour and the incomes of agricultural workers. As countries develop, farmers are likely to become richer, gain better access to credit and be more able to invest in the infrastructure required for irrigation, such as irrigation canals and equipment for surface and pressurised irrigation. Thus the share of land that is able to be irrigated and that is already equipped with the necessary infrastructure provides an indication of the capacity a country has for future investment. Higher shares indicate lower levels of investment are more likely.

Error! Reference source not found. indicates that the DRC has the largest potential for future investment in irrigation infrastructure mainly attributable to its relatively large (and unequipped) area of irrigable land, 7,000 km^2. Angola, Ethiopia and Mozambique also have large unused potential requiring over 40 per cent of that of the DRC. Several countries such as Cape Verde, Equatorial Guinea and Lesotho have no investment needs due to negligible areas of irrigable land.

The DRC has the highest potential for future investment in irrigation infrastructure



Note: Countries for which data was unavailable appear as 0.
Source: Food and Agriculture Organization of the UN (2014), Vivid Economics

Water infrastructure

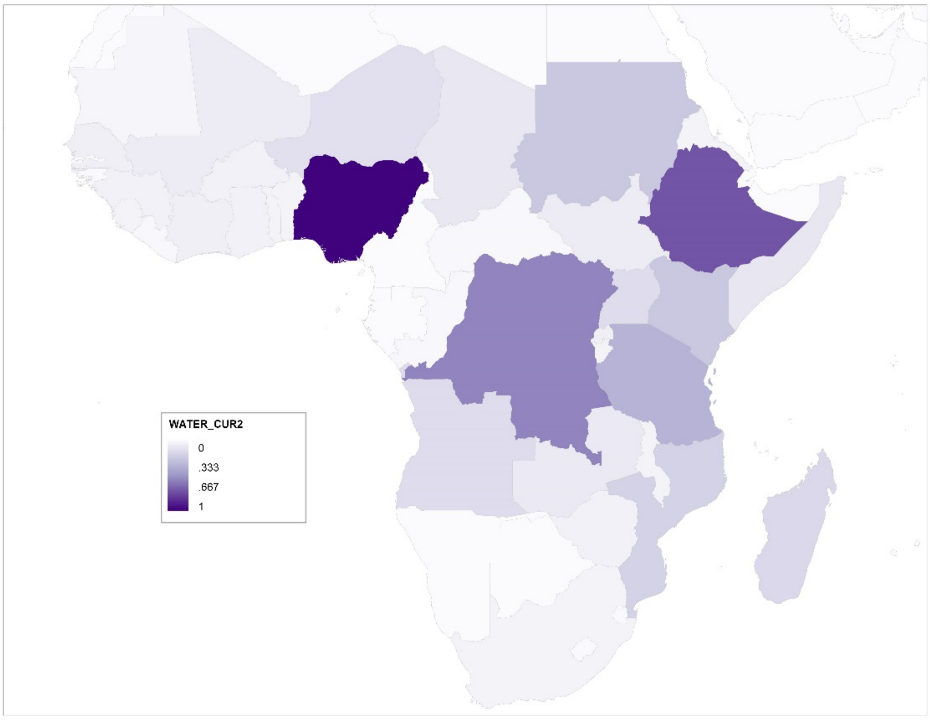
Share of population with access to improved water

Providing access to water to new communities requires a vast network of infrastructure to extract water, through water wells and reservoirs; treat water, in treatment stations; and distribute water, using pipelines and pumping stations. As infrastructure for extraction and treatment can be costly, the capacity of reservoirs or treatment stations is often large entailing significant investments. Evidence from the US suggests assets of this type have a useful life of approximately 40 years (US Department of Commerce, 2014). It can also be difficult to adjust the location of distributing infrastructure once it is built without causing significant disruptions to domestic supply. The definition of 'access to improved water' used is consistent with that of the Millennium Development Goals.

Similarly to the share of the population living in slums, the figure presents the relative levels of investment required to meet the highest share of the population with access to improved water across all developing countries, given each country's *current* population. It does not account for future growth in population. Nigeria, Ethiopia and the DRC require the highest levels of

investment owing to both large populations and low current levels of access to water. Kenya, Tanzania and Uganda all require between 20 to 30 per cent of that of Nigeria.

<u>A range of countries in the north east of Sub-Saharan Africa have mid-range investment needs</u>



Note: Countries for which data was unavailable appear as 0.
Source: World Bank (2014b), Vivid Economics

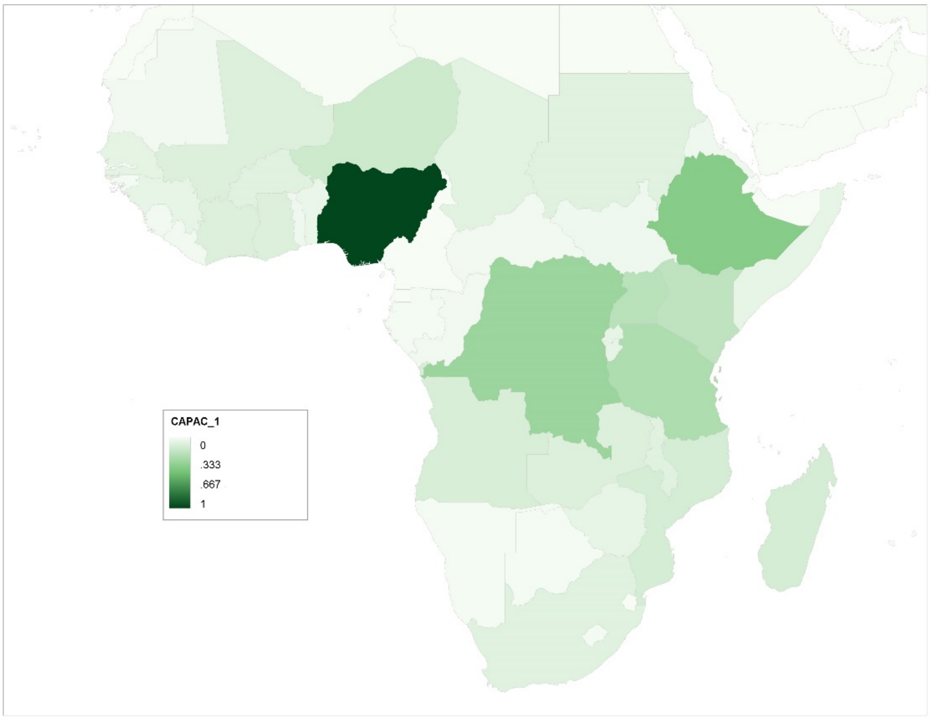
Energy and communications

Electricity generation capacity per capita

As countries develop and incomes rise, both residential and industrial demand for electricity is likely to increase as larger portions of the population are connected to national grids, consumers demand different goods and more advanced production processes are put in place. To increase the supply of electricity, investment is needed in generation, transmission and distribution infrastructure, for which useful asset lives can range from 30 to 50 years (US Department of Commerce, 2014; US Department of the Treasury, 2012).

As indicated below, Nigeria requires the highest level of investment in energy generation infrastructure due to its high forecasts of future population growth. The set of countries with mid-range investment levels is similar to that for water infrastructure suggesting that for both of these indicators, population forecasts play a key role in determining likely investment.

<u>Electricity generation capacity is likely to expand most, in absolute terms, in Nigeria, the DRC and Ethiopia</u>



Note: *Countries for which data was unavailable appear as 0.*
Source: *U.S. Energy Information Administration (EIA) (2014), World Bank (2014a), Vivid Economics*

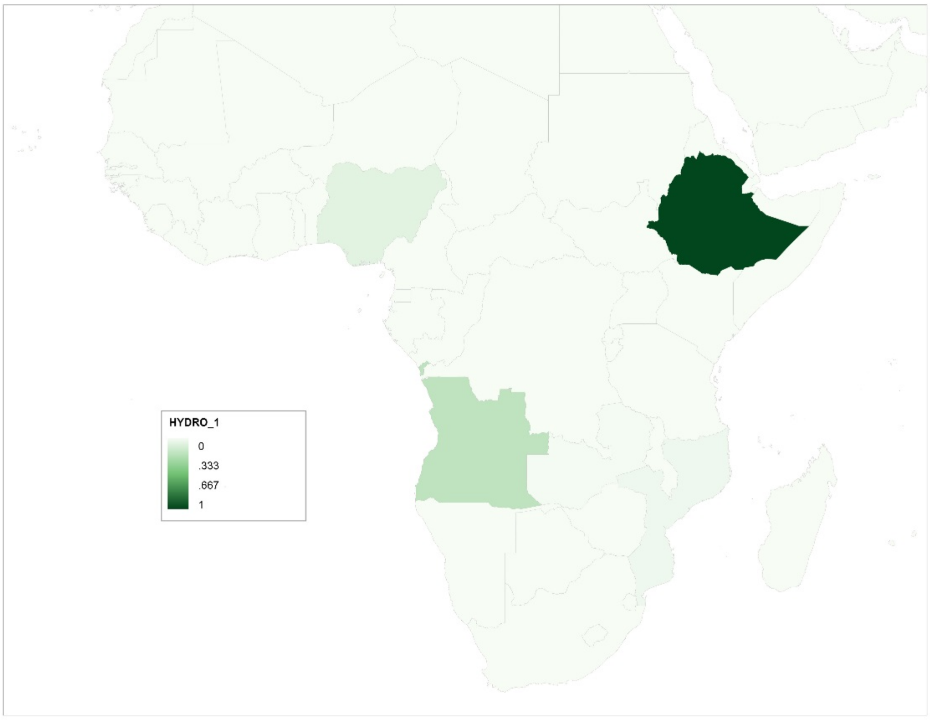
Hydropower production relative to potential

Hydropower production is a particularly capital-intensive form of electricity generation. Moreover, conventional hydroelectric plants typically have large capacities and stay in operation for long periods of time. If a country's current level of hydropower production is below its potential production, it may be assumed more likely to invest in hydropower infrastructure in the future to increase this.

Potential production is defined as the level of economically feasible potential production, that is, the potential for production where the value of the electricity generated exceeds operational costs. Where data for economically feasible potential production was not available, an assumption was made on the proportion of technically feasible potential production that is economically feasible.

There are only five countries that show likely future investment in hydropower infrastructure. This is driven by two factors: low or negligible potential for hydropower production and the paucity of data available on such potential. Ethiopia is likely to experience the most investment and has a relatively large potential at 268,000 GWh per year. Angola may have around 20 per cent of this level of investment, whereas Mozambique, Nigeria and Zambia considerably less.

Very few countries are likely to see substantial investment in hydropower



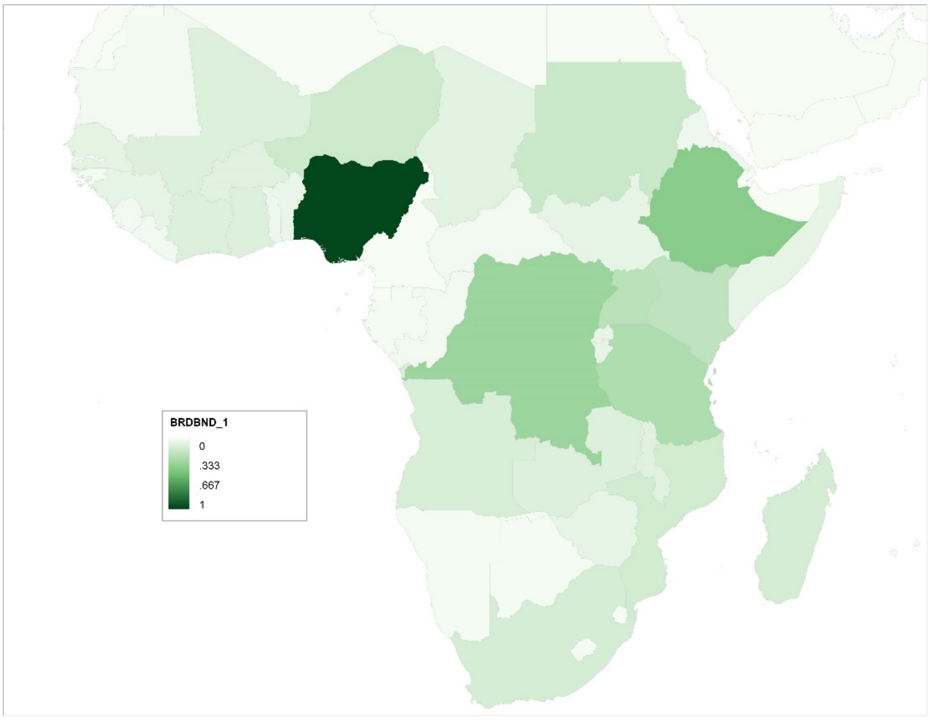
Note: Countries for which data was unavailable appear as 0.
Source: The Programme for Infrastructure Development in Africa (2010), World Bank (2014b), World Energy Council (2013), *Vivid Economics*

Fixed broadband internet subscribers per capita

As urbanisation occurs and rural settlements become more developed, demand for communications infrastructure will increase. Broadband internet is an example of a technology that is widespread in the developed world but has achieved little penetration in the developing world. It can serve as a proxy for the development of communications infrastructure more generally. The number of fixed broadband internet subscribers per capita measures the level of consumption of broadband relative to a country's population. Countries with a low number of subscribers are likely to invest in infrastructure such as telecommunications towers, with a useful asset life of 40 years (US Department of Commerce, 2014), to increase this.

The highest levels of investment in broadband internet connections will again be seen in Nigeria, the DRC and Ethiopia. Though a larger range of countries, focussed on the east coast, see investment levels upwards of 10 per cent of that of Nigeria.

Nigeria is likely to invest most heavily in broadband and wider communications infrastructure



Note: Countries for which data was unavailable appear as 0.
Source: World Bank (2014a, 2014b), Vivid Economics

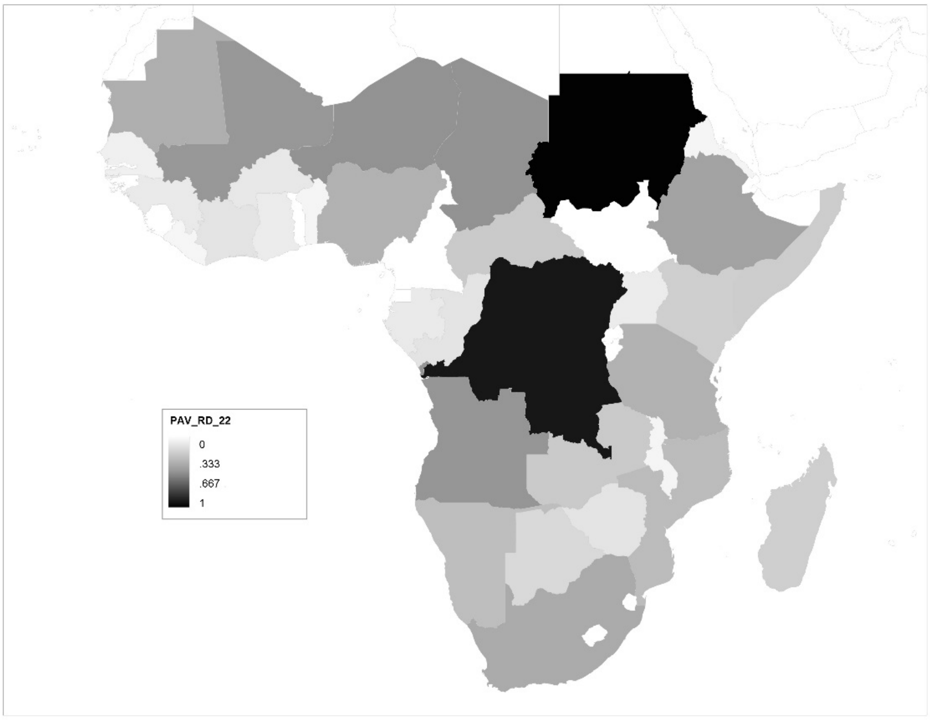
Transport

Paved road density on arable land

Paved road density on arable land is defined as the total km of paved road per square km of arable land. This is a useful measure of how well developed a country's transport infrastructure is; as countries develop, more settlements will become connected to the paved road network and built up rural settlements will become more densely populated. Paved roads are used as opposed to all roads as the both the necessary investment and asset life of non-paved roads is low. To compare this level of infrastructure across countries, the length of paved road is normalised by the total area of arable land as this excludes large areas of unhospitable land unsuitable for road construction.

In the figure we see a more even distribution of likely investment over countries in Sub-Saharan African relative to other indicators. While Sudan and the DRC will require the most investment, Angola, Chad, Ethiopia, Mali, Niger and South Africa will all experience approximately half this level. It is worth noting that several countries with a particularly small land area such as Cape Verde, Lesotho and the Seychelles have been excluded from this analysis and appear as 0.

<u>Investments in paved roads are likely to be distributed more evenly across Sub-Saharan Africa</u>



Note: Countries for which data was unavailable appear as 0.
Source: World Bank (2014b), Vivid Economics

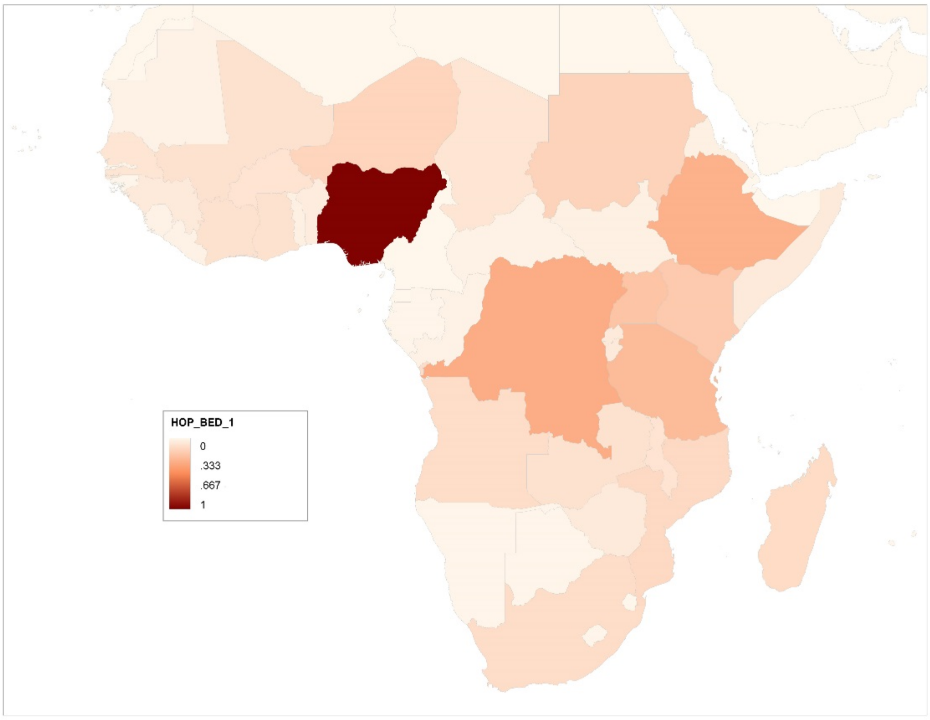
Education and health

Hospital beds per capita

The number of hospital beds per capita is a useful indicator of both the stock of long lived infrastructure to provide health care and the quality of health care as it approximates the floor area of functioning hospitals. As countries develop, it may be that the population places more scrutiny on the provision of public services and the quality of health care improves as a result. This will require substantial investment in hospital buildings which have a typical useful asset life of 36 years(US Department of Commerce, 2014).

In terms of likely investment in health infrastructure, Nigeria requires a substantial amount more investment than any other country. The figure shows Ethiopia, the DRC and Tanzania, the subsequent three highest countries, are likely to invest only 30 per cent of that of Nigeria. Again, this is driven largely by forecasts of future population growth.

Nigeria will invest 70 per cent more in health infrastructure than the next highest country



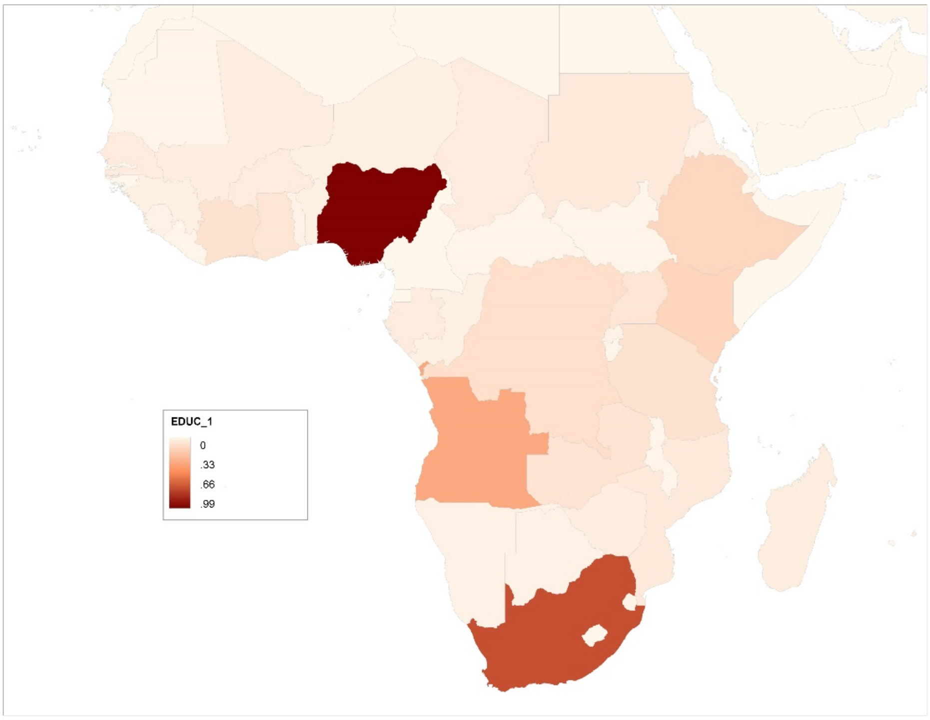
Note: *Countries for which data was unavailable appear as 0.*
Source: World Bank (2014a, 2014b), *Vivid Economics*

Public spending on education as a share of GDP

Schools are typically built solely from public funds and require several years to plan and construct. As a result, public spending on education is a good leading indicator of when investment in school buildings is likely to occur. Examining the level of public spending as a share of GDP provides an approximation of the quality of the education system and hence, is a useful metric to compare levels of development. As countries aim to improve the quality of their education system, they are likely to increase public spending on education as a share of GDP and invest in infrastructure for education.

As the figure indicates, while Nigeria again has the highest levels of likely investment for educational infrastructure, South Africa is also likely to invest up to 70 per cent of that of Nigeria. This is driven largely by the relatively high level of both countries' GDP. Angola may also invest around 40 per cent while most other countries experience a relatively small investment.

South Africa may invest up to 70 per cent of that of Nigeria in educational infrastructure



Note: Countries for which data was unavailable appear as 0.
Source: IMF (2014), World Bank (2014c), Vivid Economics

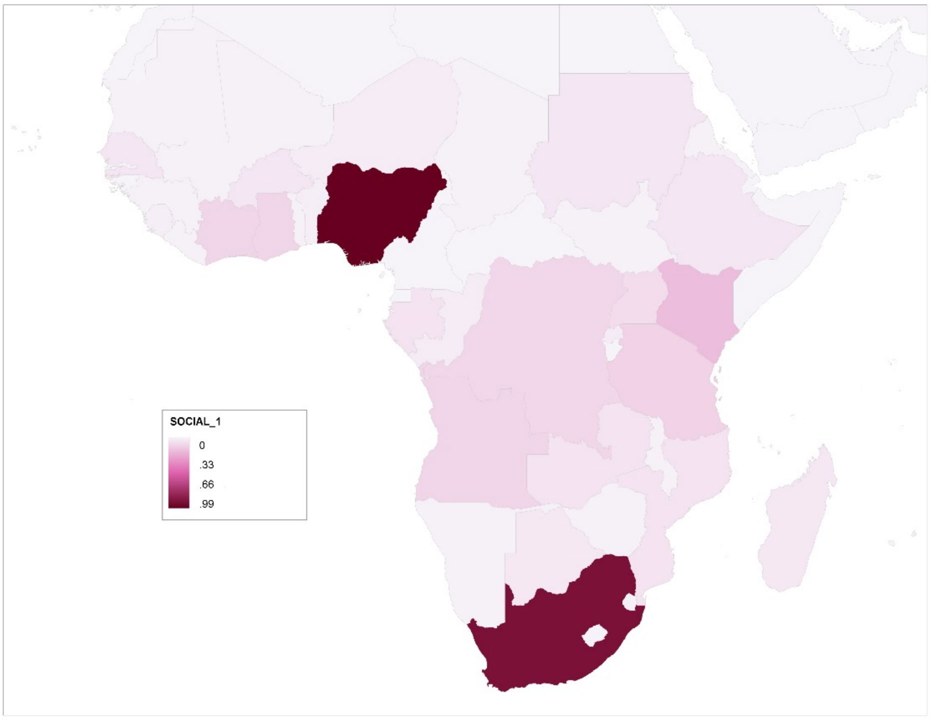
Insurance and social protection

Total spending on social and labour protection measures as a share of GDP

Social and labour protection measures often require several years of planning and substantial amounts of technical infrastructure to implement and monitor. Moreover, as their coverage is often national in size, they can be difficult and costly to adjust in the future. More developed countries are often associated with a more sophisticated, and generous, social safety net and so it is likely, as countries develop, that there will be significant investment in these protection measures.

The figure suggests that the expansion of social and labour protection measures has a relatively muted effect on countries other than Nigeria and South Africa. Again, this is likely to be due to the differences in the level of GDP, as most countries in Sub-Saharan Africa will be starting from a relatively low level of GDP and hence incremental increases in the proportion of GDP spent on protection measures will cause relatively small changes in absolute spending.

South Africa and Nigeria will spend the most on social and labour protection measures



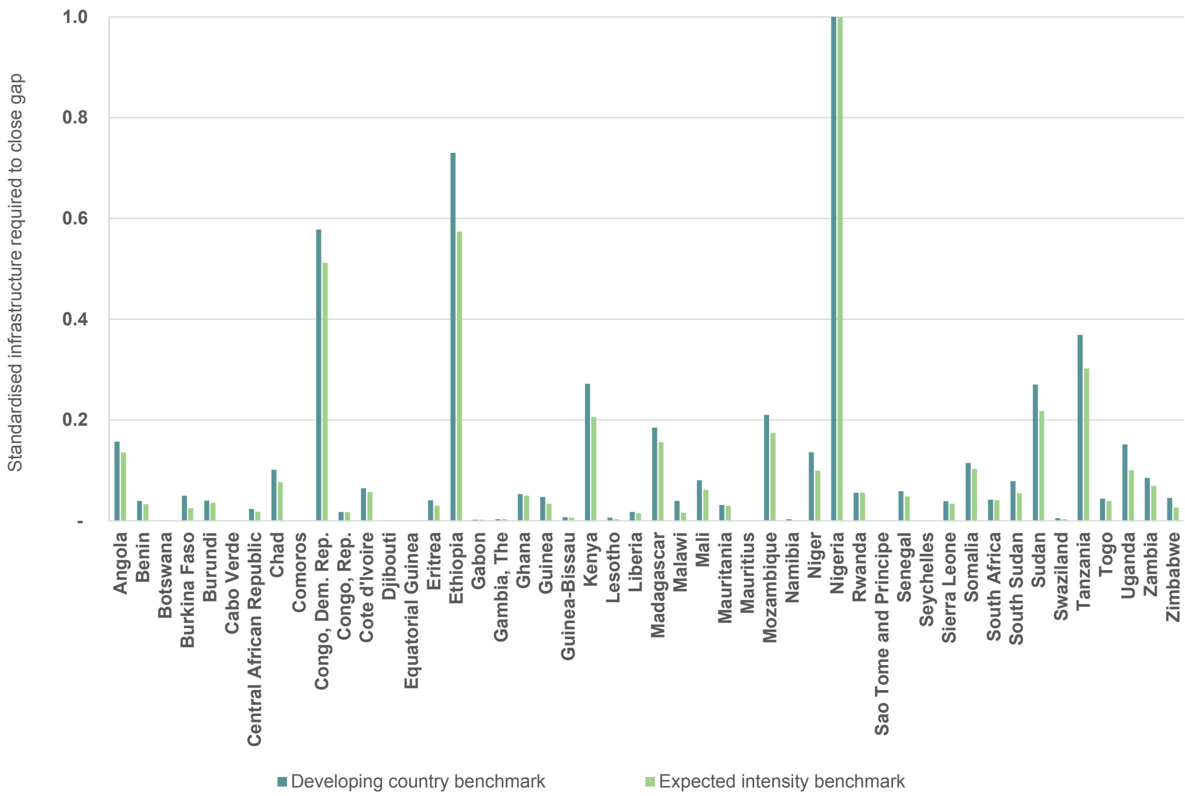
Note: Countries for which data was unavailable appear as 0.
Source: IMF (2014), World Bank (2014b), Vivid Economics

Barriers to closing infrastructure intensity gaps

As mentioned earlier, it is also possible to calculate infrastructure intensity gaps relative to what we might expect a country's infrastructure intensity to be, given its level of development and other national characteristics. This provides an additional insight to the results by controlling for the effect that such characteristics might have on a country's infrastructure intensity. This does not mean that the intensity gap will always be smaller when using expected intensities, as, while an increase in some characteristics will cause a given infrastructure intensity to rise, others will cause it to fall. However, one of the particular effects of controlling for national characteristics in this way is to 'clean out' of the results intrinsic limitations to investment.

The figure below contrasts the results using both methods for the share of the population with access to improved water. The relative levels of investment required to close the intensity gap follow a similar pattern across countries. However, those calculated with reference to the expected intensity are almost always slightly lower. This provides support for the method used in the core analysis, suggesting that the gaps identified for access to improved water are indeed more likely to be closed.

<u>The results for access to water are broadly consistent across both benchmark methods</u>



Note: Results from each benchmark method are standardised by the total range of infrastructure investments.
Source: World Bank (2014d), Vivid Economics

Even this alternative approach to benchmarking, however, may fail to capture all relevant factors affecting the propensity to invest in national infrastructure. Poor access to finance, an unfavourable investment climate or ineffective governance can all prevent a country from securing the necessary investment to close the infrastructure intensity gaps identified in this analysis. Some of these indicators are included in the econometric analysis of Yepes et al. (2008), yet statistical problems such as identification and correlation of regressors may prevent their effects from being properly accounted for.

To better understand how this might influence the conclusions drawn from this analysis, three indicators are examined for each country: a composite credit rating, the level of domestic credit provided by the financial sector and the average score from the 2014 World Governance Index (WGI) update. The first two of these indicators relate to a country's access to finance whereas the latter relates to the quality of governance.

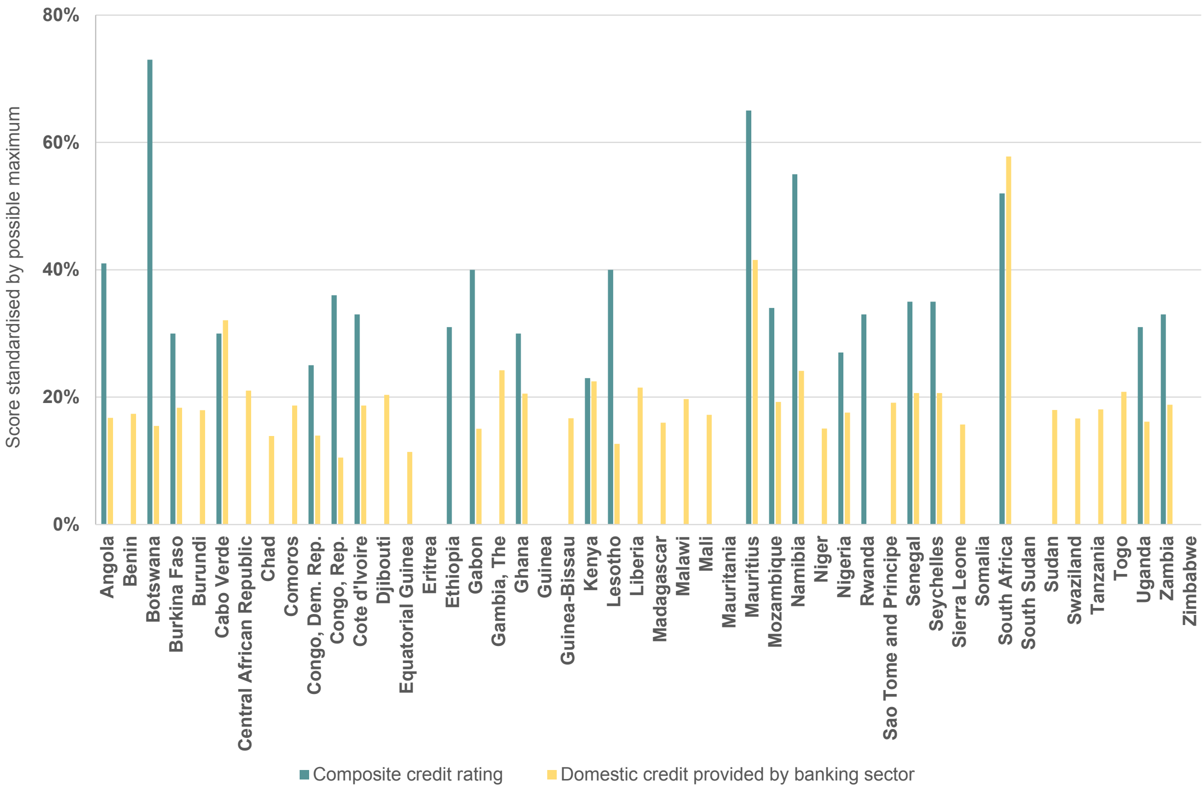
The composite credit rating is based on an assessment of a country's rating with all three major institutions – Standard and Poor's, Moody's and Fitch– as well as the perceived stability of those ratings (Trading Economics, 2014). This assessment is then translated into a score out of 100. Therefore, the composite rating provides an indication of how easy it is for a country to raise finance through international capital markets, as well as the likely costs of borrowing. Both of these factors will play a prominent role in many countries' public investment plans.

The amount of domestic credit provided by the financial sector as a percentage of GDP provides an indication of how well developed the domestic financial sector is. Similarly, this will have

direct impacts on the quantity and cost of credit available in the economy, both to the public and private sector.

The figure below compares standardised values of these two indicators for countries in Sub-Saharan Africa. The composite credit rating is standardised by the maximum possible score whereas domestic credit is standardised by the highest value across all (developed and developing) countries. Most Sub-Saharan African countries struggle to score more than 40 per cent on either indicator. Some of the countries that were repeatedly identified as having the highest investment requirements – Nigeria and the DRC – have some of the lowest scores on both indicators, broadly 25 per cent for the composite credit rating and 15 per cent for domestic credit. This is suggestive that while there may be a large requirement for investment if these countries are to meet the infrastructure intensity benchmark identified, they may have difficulty in doing so. One of the highest scoring countries in both indicators is South Africa which had high investment requirements for both educational and social safety net infrastructure. Taken together this suggests that there is likely to be high levels of this type of investment in South Africa in the future.

The pattern of access to finance does not match that of investment needs



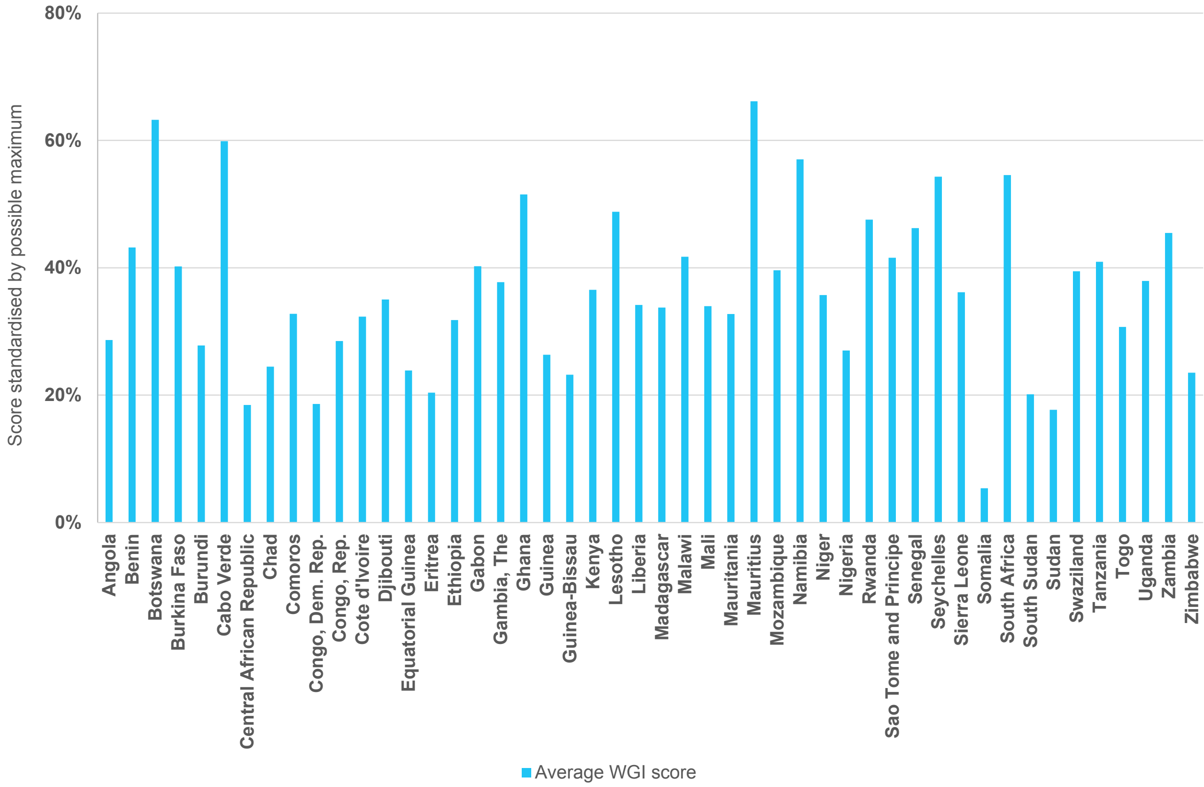
Note: *The maximum possible value for domestic credit was taken as the maximum value globally.*
Source: *Trading Economics (2014), World Bank (2014d), Vivid Economics*

The World Governance Index reports indicators for 215 economies covering six key areas of governance: voice and accountability; political stability and absence of violence; government effectiveness; regulatory quality; rule of law; and control of corruption. These are based on 32 individual data sources and produced by a variety of surveys, institutes, think tanks, NGOs, international organisations and private sector firms (World Bank, 2014e). This analysis takes the

average of the best estimate of each indicator to provide a composite indicator of governance quality. Much large-scale infrastructure investment is undertaken by government and government institutions must be effective to successfully plan, finance and implement such investments. Hence, a country's average WGI score is a good indicator for the likelihood that infrastructure investment needs will be met. This average score is then standardised by the maximum possible score a country could achieve to give a percentage value.

A similar pattern to access to finance is seen with the average WGI score below. Most countries do not score over 40 per cent and those countries that were repeatedly identified as having the highest investment requirements score in the lower half. This suggests that the distribution of investment among Sub-Saharan African countries may, in reality, be different from what the conclusions drawn from the main analysis suggest.

The WGI scores show a relatively similar relationship across countries as access to finance



Source: World Bank (2014e), Vivid Economics

Conclusions and next steps

Initial conclusions

Looking across the indicators of infrastructure intensity as a whole, Nigeria appears to have the highest absolute investment needs in Sub-Saharan Africa – indeed, it has the highest needs for nine of the twelve indicators examined often by a significant margin. Ethiopia and the DRC also score highly on a wide range of indicators pointing to a relatively high overall level of investment needs. In all three cases, the key driver of this is the large size of the country both in terms of population and land area. As each infrastructure intensity gap is multiplied by the absolute value of the variable underlying the intensity to arrive at an absolute level of investment, even if other

countries have a larger gap, the much larger underlying variables seen in these three countries lead to a larger level of investment need. This effect becomes more pronounced when considering forecasts of these variables such as city population growth.

However, these same countries typically perform poorly when looking at the enabling environment for infrastructure investment. Composite credit ratings are roughly around the midpoint of Sub-Saharan Africa indicating each country has poor access to finance from international sources while the level of domestic credit available is within the lowest quartile suggesting resources available domestically are even scarcer. These countries also have an average WGI score between 20 and 30 per cent which may mean that even with favourable investment conditions, public institutions may fail to organise and implement such investments. Overall, it seems that Nigeria, Ethiopia and the DRC are likely to experience some investment in long-lived infrastructure in the medium term, particularly concerning urban planning, housing and amenities however, there are unlikely to be the leaders of Sub-Saharan Africa that the main analysis suggests.

Two particular intensity indicators that provided a different perspective were the share of irrigable land equipped for irrigation and hydropower production relative to potential. Within both, only a small subset of countries were likely to experience any significant investment in the future. While the DRC still had the highest investment needs for irrigation and Ethiopia for hydropower, other countries such as Angola, Mozambique and Zambia also required a substantial amount of the leaders' needs. These three countries scored moderately on both the investment climate indicators and the quality of governance indicator suggesting that moderate levels of investment in infrastructure in these sectors is likely.

South Africa had relatively high investment needs for both educational and social protection infrastructure. Similar to the effects of Nigeria's large population, this was caused primarily by South Africa's relatively high GDP which caused even a modest intensity gap to translate to substantial absolute investment needs. South Africa also scored relatively highly in both the access to finance indicators and the average WGI score suggesting that if there was sufficient demand, the opportunity for investments is available. Overall, this indicates that significant investment is likely to occur in infrastructure to provide both education and social and labour protection in the future.

Next steps

This report presents has presented a summary of the methodology used for the analysis, the initial findings and conclusions however, the analysis is ongoing. Specific aspects of the assessment methodology and hence, the conclusions drawn will continue to be refined. For the next draft, we propose to undertake the following changes.

For each intensity indicator, we will refine the set of comparison countries to exclude outliers which may exaggerate the investment needs of Sub-Saharan African countries. This will be done by examining a related variable and truncating the dataset by a sensible value, for example, in the case of paved road density, any country with a total land area of less than 1,000 km2 was excluded.

To ensure we are looking at the most relevant timeframe for the project, we will restrict forecasts of the underlying absolute variables such as population and GDP to 10 years in the

future. This will also help to ensure there is consistency across the intensity indicators examined.

The investment needs to maintain the share of population living in slums and with access to water at the benchmark level in the future will also be added. This was not included in this draft due to time constraints.

To ensure that the analysis does not rest too heavily on the infrastructure gap framework, two new absolute indicators will be added – planned additions to hydropower capacity and the area of land predicted to change from rural to urban. This will help to address the weaknesses in the gap analysis, namely that gaps may persist as it is difficult to secure sufficient invest to close them.

Within each of the chloropleth maps, we will distinguish between those countries that appear as 0 because they require no investment and those that appear as 0 because there is no data available.

For each of the chloropleth maps, the key will be enlarged so it is more readable and the heading including the code name will be removed.

TASK 2: PRACTICAL EXAMPLES OF LONG-TERM DECISIONS

The aim of this task is to identify any practical examples in the grey or peer-reviewed literature of where the economic analysis of long-term decision making has been particularly good, preferably in areas directly relevant to adaptation in Africa or failing this in other relevant areas. The starting point for this task has been to compile the study team's existing inventories of adaptation economic studies in Africa, and more generally, economic analysis of long-term decision making for adaptation.

Studies on the Economics of Adaptation in Africa

Previous reviews of the costs and benefits of adaptation (OECD, 2008; UNFCCC, 2009; Agrawala et al, 2011; Chambwera et al., 2014) generally report that the evidence base on the costs and benefits is low. However, over recent years, additional evidence has emerged. This is due to a large number of global and country level initiatives on the economics of adaptation, and also sectoral studies that apply existing options to new contexts or locations. A recent review and compilation of these studies (ECONADAPT project, 2015) has identified several hundred studies. Over recent years, a number of initiatives have emerged that provide estimates of the early costs of adaptation in Africa. The coverage is shown below.

National and sub-national level adaptation cost studies in Africa

National assessments or initiatives — Other studies with national or sub-national coverage

Source: ECONADAPT, 2015.

Four key initiatives have been undertaken: the World Bank EACC country studies (World Bank 2010), UNDP Assessment of Investment and Financial Flows (IFF) to Address Climate Change (UNDP, 2011), the UNFCCC National Economic, Environment and Development Study (NEEDS) (UNFCCC, 2010) and the Regional Economics of Climate Change Studies (RECCS). These studies

use different methods, and have different assumptions, making direct comparison difficult. Nonetheless they provide some useful information for the current study.

The World Bank Economic of Adaptation to Climate Change (World Bank, 2010) study used global scenario-based impact-assessment to estimate the economic costs of climate change, then estimated the costs of adaptation to achieve pre-climate levels of welfare. The study considered two climatic futures, with minimum and maximum temperature and 'wetter' and 'drier' rainfall outcomes, finding that higher costs arose with wetter scenarios due to impacts on infrastructure. The choice of aggregation rule also affected the estimates, notably whether gains from climate change were added to adaptation costs. The study included an explicit consideration of future development baselines, as well as the effects of climate change by sector, and did consider (climate) uncertainty. However, as the report acknowledges, adaptation costs were still calculated as though decision-makers know the future with certainty, with estimates calculated for each discrete projection in turn: in reality costs would be higher due to the need to hedge against a range of outcomes. Furthermore, the coverage of impacts and sectors is partial (and similar to the UNFCCC study) focusing on a small number of impacts (albeit important ones), i.e. where quantification was possible.

The global study reported that the costs of adaptation for Sub Saharan Africa – for the period 2010 to 2050 (thus for a 2°C warmer world) – were USD 14 billion to USD 17 billion per year (2005 $ billions, no discounting). This compared to global costs in developing countries of USD 71 billion to USD 98 billion (about the same order of magnitude as current foreign aid). This value was cited in the IPCC 5th Assessment Report, though this acknowledged the short-comings with the value.

The global study was complemented with a number of country studies – of which three were in Africa (Ethiopia, Ghana and Mozambique). These also used sector impact assessment though also included wider economic modelling. The studies used the DIVA model for sea-level rise, agricultural crop models, water management models, and some infrastructure damage functions. These country studies indicate higher costs than the global study, around 20% higher due to the consideration of cross-sectoral and socially contingent effects. However, in some cases, the country studies indicated very much higher costs than the global analysis. For example, the country study in Ethiopia (World Bank, 2010) estimated the costs of adaptation and the residual impacts for this one country alone could be $1.2 billion to $5.8 billion per year (2010 – 2050). Similarly, the costs for Mozambique for addressing sea level rise (World Bank, 2010c) were estimated at $0.3 to $0.8 billion per year by the 2030s.

An alternative set of country analysis was produced under the UNDP Investment and Financial Flows to Address Climate Change initiative, which used a different method, centred on investment and financial flows, i.e. estimating adaptation mark-ups on future investment profiles. These studies estimate the additional adaptation costs required through to 2030. A total of 15 country studies were undertaken, with African studies in Gambia, Liberia, Namibia, Niger, Togo, each focusing on 1 or 2 key sectors each (primarily agriculture and/or water).

Again, these costs indicate higher costs than implied by the global assessments. This can be explained partly by the different methods, assumptions and coverage. The IFF studies are better grounded in current policy and they include a much greater coverage of risks as they look to build resilience across all existing policy areas. They also have a more realistic assessment of costs of delivering adaptation (including implementation and policy costs, and the costs to the

private as well as the public sector) and they do not aggregate winners and losers. However, they include some costs for action that are targeted at reducing the existing adaptation deficit, they often are often focused on irrigation options, and they omit the benefits of trade in offsetting the need for domestic action.

Summary of the UNDP IFF assessments – total additional investment costs (USD to 2030)

Country	I&FF assessments and results	Estimated costs
Gambia	Agriculture – and water adaptation	US$ 435 million [$ 1440 undiscounted] is needed to adapt to the effects of climate change in the agriculture sector, and US$ 17 million is needed to adapt to the effects of climate change in the water sector.
Liberia	Agriculture - adaptation	For the agriculture / livestock sector (adaptation to the impacts of climate change) US$ 1.41 billion is needed to adapt to the effects of climate change.
Namibia	Land-use change - adaptation	For the land-use sector (adaptation to the impacts of climate change), the overall incremental costs of the measures are US$3.0 billion (livestock and crops) [discounted].
Niger	Agriculture/livestock - adaptation	For the agriculture / livestock sector (adaptation to the impacts of climate change) US$ 374 million is needed to adapt to the effects of climate change in the agriculture/livestock sector.
Togo	Agriculture - adaptation	The I&FF assessment on the agriculture sector focused on crops, livestock and fisheries. US$ 167 million are needed to protect agriculture against the impacts of climate change.

Source: UNDP (2010)

A further study – the UNFCCC NEEDS project was undertaken in a number of countries including Egypt, Ghana, Mali and Nigeria (UNFCCC, 2010). This assessed the short- and long-term costs of adaptation financing needs. These studies also indicate high individual country estimates, though the countries used different methodologies and approaches, over different time-scales.

Aggregated estimated short- and long-term financial costs of adaptation as reported by countries participating in the National Economic, Environment and Development Study for climate change project

Country	Short-term costs (2020)	Long-term costs (2050)	Comments
Egypt	2.8 billion	4 billion	Cost estimates cover observation systems, agriculture, irrigation, coastal zones, socioeconomic studies of the cost of adaptation, and capacity-building and training.
Ghana	697.2 million	701.7 million	Estimates of the cost of containing the effects of climate change on health, agriculture and coastal zones
Nigeria	11.45 billion (annually)	20.69 billion (annually)	Estimated incremental costs of adaptation measures in relation to water, agriculture, health and transportation

Source UNFCCC, 2010.

Alongside this, a large a number of other regional and country level initiatives have been undertaken, including the RECC studies in Kenya and Rwanda (SEI, 2009) and Tanzania (GCAP, 2010), and also studies in Ethiopia (Watkiss et al, 2013; FDRE, 2015), Tanzania (GoT, 2014) and Uganda (CDKN, forthcoming).

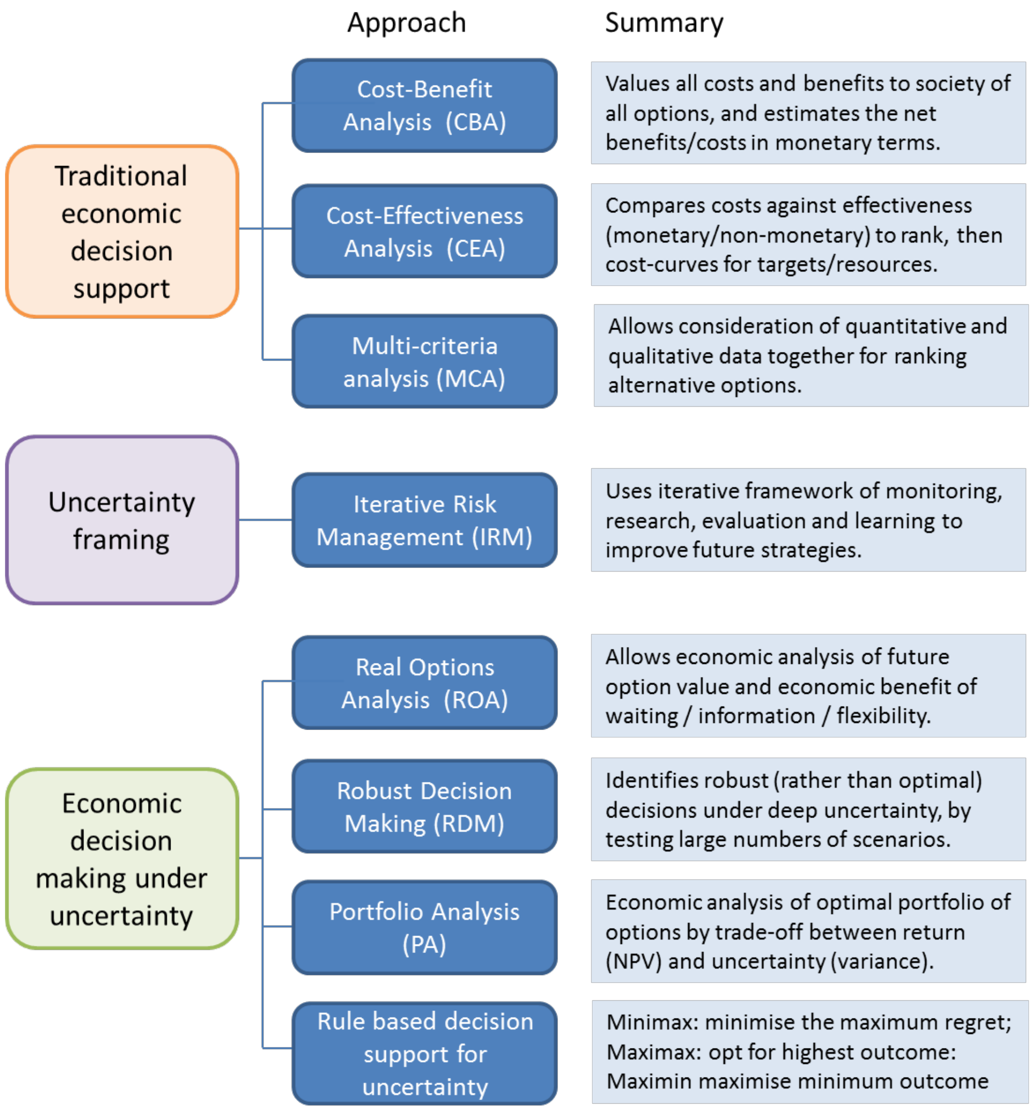
Other studies include:

- Application of the DIVA model to all African countries, with disaggregated costs of sea level rise and adaptation costs (Brown et al, 2009). Consideration of the risks and adaptation costs for 136 global coastal cities (of which Abidjan, Alexandria, Algiers and Banghazi in Africa were identified as priorities) (Hallegatte et al, 2013). At a more localised level, there is the study of adaptation in coastal zones in Durban, South Africa (Cartwright et al, 2013).
- Some estimates of the costs of adapting existing building new climate-proofed urban water infrastructure in (sub-Saharan) Africa (Muller, 2007) estimated at US$ 2-5 billion annual. AfDB (2011) and Doczi and Ross (2014) review other estimates for Africa in this area. There is also the study of water infrastructure investment in the Berg River, South Africa (AIACC, 2006), and water resource management in Kenya (SEI, 2009) as well as Ethiopia (World Bank, 2010) and in the water sector in Morocco (Mohamed, 2013).
- For agriculture, the application to agricultural adaptation in Gambia (AIACC, 2006), adaptation cost-benefit curves in Mali, Mopti on climate shifts (ECA, 2009), benefit cost analysis for agriculture in Malawi (Branca et al, 2012) and agricultural CBA in Uganda (IIED, 2012), as well an economic analysis of adaptation (using stakeholder CBA) in the Lake Chilwa Catchment in Malawi (Lunduka et al, 2013) and on climate smart agriculture (McCarthy et al., 2011), as well as several Ricardian studies (Kurukulasuriya et al., 2007; 2008; 2011) and the EACC crops models and IFF assessments. There is also the Tanzania agricultural sector adaptation plan (Government of Tanzania, 2014
- Adaptation cost studies on road infrastructure in developing countries, including in Ethiopia and Ghana (World Bank, 2010).
- Analysis of health adaptation in Tanzania for water related disease (ECA, 2009) and Kenya for malaria (SEI, 2009).

Most of these estimates are from the grey literature. Moreover, most of the evidence is based on classic scenario-based impact assessment methods. This means the majority of the studies are theoretical, focus on technical adaptation, and ignore uncertainty. These earlier studies show adaptation has very high BCRs and potentially low costs, though more recent studies indicate they are probably over-optimistic. In terms of adaptation decision making under uncertainty, there are only a limited number of studies found for Africa, discussed in the next section.

Studies on Long-term Adaptation Decision Making

This is a growing evidence base and examples on the use of decision support approaches for adaptation appraisal, though as shown above, the number of such studies in Africa is small. These tools are a key component of the consideration of adaptation in medium to long-term climate decisions. They include conventional decision support methods, notably cost-benefit analysis, cost-effectiveness analysis and multi-criteria analysis. It also includes a set of approaches that allow for consideration of uncertainty, notably real options analysis, robust decision making, portfolio analysis and iterative risk management. A detailed description and review of these methods and their application to adaptation, has been undertaken as part of the MEDIATION and IMPACT2C projects (see also Watkiss et al, 2014: Ranger et al, 2010: Frontier, 2013). They are summarised below.



Decision Support Tools for Adaptation

Source: ECONADAPT, 2015, updating Watkiss et al., 2014.

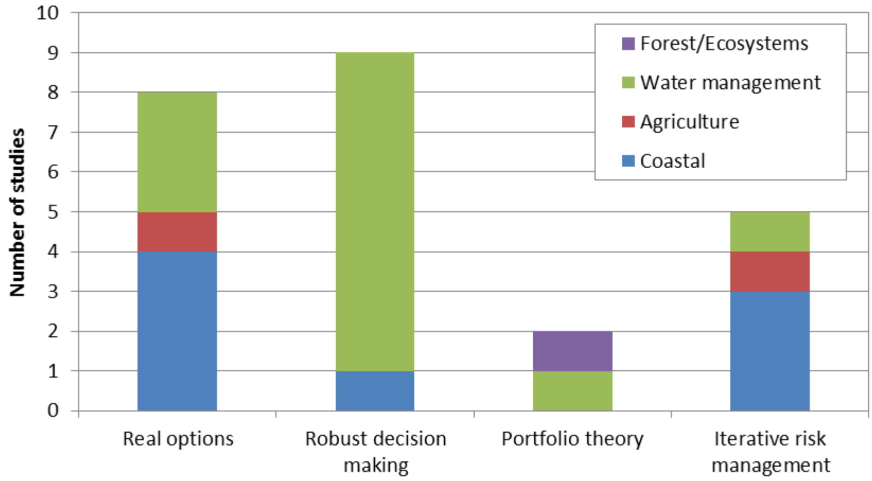
Whilst these tools have primarily been developed in the context of project-level appraisal, in principle they can be used to prioritise policy initiatives at the national and sectoral scale (though principally as an organising framework, with semi-quantitative versions due to data availability). At the project level, where data is available, they can be applied more quantitatively. Examples are given below.

Examples of Appraisal Methods in the Adaptation Context

Tool	Published Example Applications
Cost-Benefit Analysis	AIACC (2006). This South African study examined the benefits and costs of avoiding climate change damages through structural and institutional options for increasing water supply in the Berg River Basin in the Western Cape Province. The UBA (2012) project applied cost-benefit analysis to consider 28 adaptation options for Germany.
Cost-Effectiveness Analysis	Boyd et al (2006) undertook a detailed application of cost-effectiveness for water resource zones and the adaptation response to address household water deficits in the UK. Tainio et al. (2013) investigated the cost-effectiveness of adaptation options that could maintain the biodiversity of Finnish semi-natural grasslands under a changing climate.
Multi-criteria analysis	Van Ierland et al. (2007) (De Bruin et al. (2009) applied MCA to assess adaptation options for the Netherlands as part of the Routeplanner national study. This used a qualitative MCA, which included various adaptation criteria. A quantitative MCA was used in the Thames Estuary 2100 project (EA, 2009: 2011) as part of a broader study looking at future coastal flood defences for London. The MCA was used to include qualitative criteria (environment, heritage, etc.) alongside formal economic cost-benefit analysis.
Real Options Analysis	Jeuland and Whittington (2013) applied real option analysis for a water resource planning case study (large water storage projects) in Ethiopia along the Blue Nile. Van der Pol, et al (2013) looked at optimal dike investments under uncertainty with learning about increasing water levels. Linquiti and Vonortas (2012) analysed coastal protection investments and found using real options led to better use of resources in Dhaka and Dar-es-Salaam. Scandizzo (2011) applied ROA to assess the value of hard infrastructure, restoration of mangroves and coastal zone management options in Mexico. Kontogianni et al (2013) used ROA to assess the value of maintaining flexibility (e.g. scaling up or down, deferral, acceleration or abandonment) to engineered structures in Greece. Gersonius et al, 2013 applied to water and flood risk infrastructure in an urban site in the UK, Dobes, 2010 applied to housing design for flooding in Mekong Delta Vietnam and World Bank 2009 applied to agricultural irrigation in Mexico.
Robust Decision Making	A comprehensive, formal application of RDM was undertaken by Lempert and Groves (2010) for Southern California's Riverside County Inland Empire Utilities Agency (IEUA). There is an application of robust decision making for planning coastal resilience for Louisiana (Groves and Sharon, 2013), an application to water scarcity in the Colorado River Basin (Groves et al, 2013) and to flood risk management in Ho Chi Minh City in Vietnam (Lempert et al, 2013). Dessai and Hulme (2007) present an example of the application for RDM to look at climate uncertainty for water supply management in the UK. Nassopoulos et al (2013) applied to dam dimensioning for a small catchment in Greece. Dyszynski and Takama (2010) applied RDM to micro-insurance in Ethiopia.
Portfolio Analysis	Crowe and Parker (2008) provide an application of the approach for forests, to investigate genetic material that could be used for the restoration or regeneration of forests under climate change. Hunt (2009) applied portfolio analysis to a case of flood management at the local geographical scale, for river flood risks in the UK, looking at portfolios of hard and soft options
Iterative Risk Assessment	The Thames Estuary 2100 project (EA, 2009: 2011: Reeder and Ranger, 2011) developed a tidal flood-risk management adaptation plan for London using an iterative planning approach and adaptation pathways, with a detailed monitoring and evaluation strategy. In the Netherlands the Delta programme has included consideration of river flooding (Delta Programme, 2008: 2011: 2014) moved to dynamic adaptation pathways. An iterative approach for port development comparing upgradeable versus one off investments was undertaken by the IFC (2011) on the port of Cartagena, Colombia. Watkiss et al (2013) applied an iterative approach to the development of the Climate Resilience Strategy for Agriculture in Ethiopia. Darch et al. (2011) assessed the effects of long term climate uncertainty on water investment planning in London and look to identify robust options for supply and demand and develop decision pathways

Source: ECONADAPT, 2015.

A recent review (ECONADAPT, 2015) has found that the number of economic applications of the new tools remains low, though there are examples in several sectors.



Economic application of new decision support tools for adaptation.

Source: ECONADAPT, 2015.

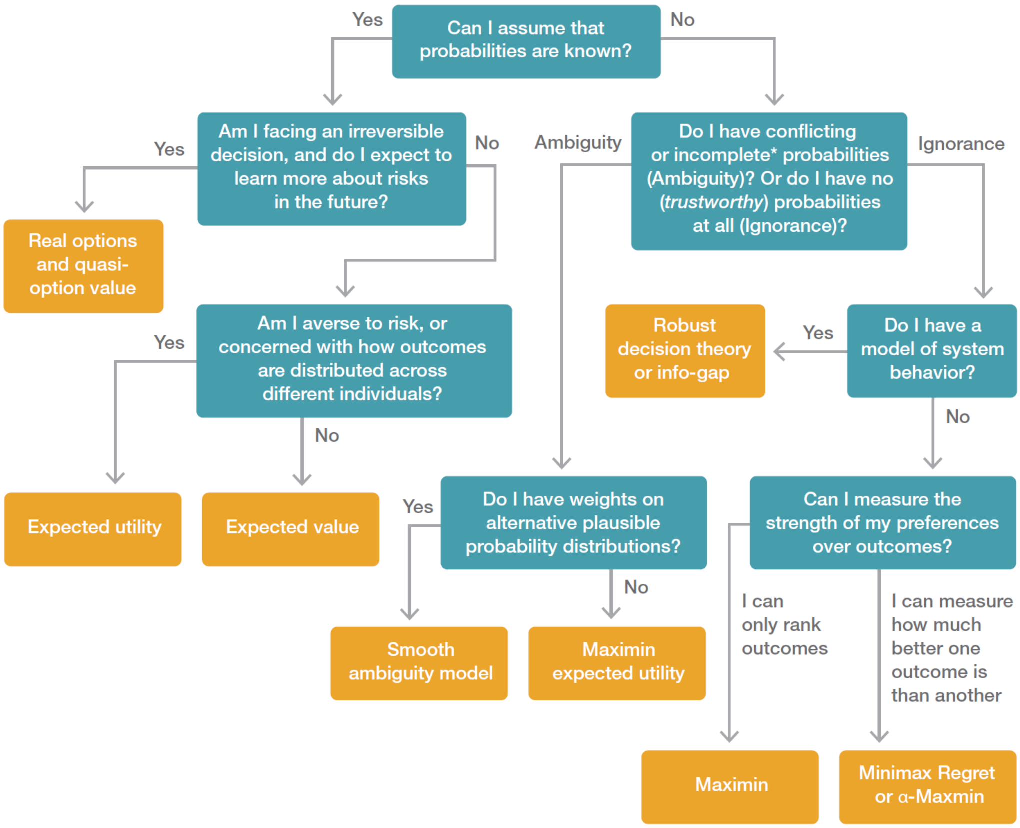
A small number of the new decision support tools have been applied in Africa.

- There is a study that uses real options analysis for the Blue Nile in Ethiopia (Jeuland and Whittington, 2013) for water investment to identify flexibility in design and operating decisions for a series of large dams. Their results do not identify a single 'best' investment plan, but highlight configurations robust to poor outcomes but flexible enough to capture upside benefits of favourable future climates.
- Linquiti and Vonortas (2012) analysed coastal protection investments and found using real options led to better use of resources in Dhaka and Dar-es-Salaam.
- Dyszynski and Takama (2010) applied RDM to micro-insurance in Ethiopia.
- There is Ethiopian Climate Resilience Strategy (Watkiss et al., 2013; FRDE, 2014) which used an iterative management approach. The approach highlighted that under conditions of high future change (e.g. high warming scenarios or early negative impacts on crops), costs post 2020 would rise more quickly, as portfolio options would need to be brought on stream quicker. Importantly, the analysis identified some areas of long-term risk that warranted early action (i.e. now), notably for coffee, due to the longer crop cycles and the long time-scale for changes in cultivar or areas.
- There is a study that considers (and costs) agricultural options using iterative adaptive management planning in Malawi (Matiya et al., 2011).

An analysis of these broader list of studies reveal that most economic applications are hypothetical studies, often focused on technical adaptation, with less applications in direct project or policy appraisals (e.g. for real schemes or sectors). The more applied studies include the application of iterative risk management in national policy appraisal in the Netherlands (iterative management for the Delta Programme, 2014) and Ethiopia (in the National Climate Resilience Strategy: FDRE, 2014), and also at the project level with the application to the London Thames Estuary 2100 project (EA 2009: 2011). It also includes applications of robust-decision making to water management in the Colorado river (Groves et al, 2013), flood risk management

in Ho Chi Minh City in Vietnam (Lempert et al, 2013) and planning coastal resilience for Louisiana (Groves and Sharon, 2013). While real-options analysis has been applied in practice in the mitigation domain, the application to adaptation remains theoretical, as is portfolio theory: ROA has also focused on sea level rise, which is easier to assess due to its slow-onset nature, and known direction of change.

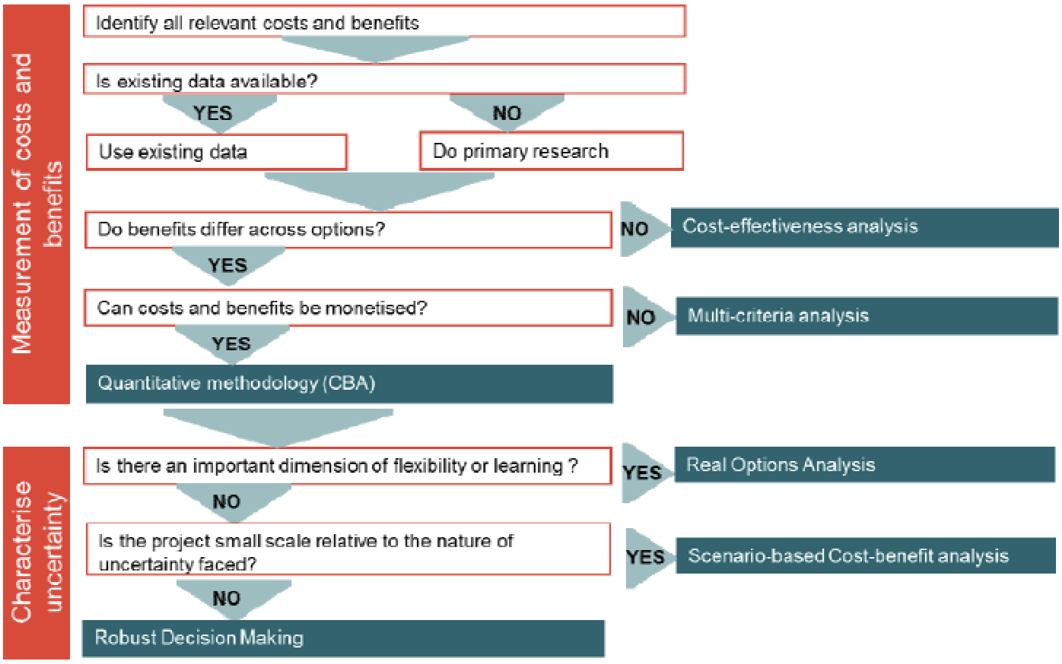
There has also been work on the potential applicability of these approaches, as part of decision support. Ranger et al. (2010) presented a framework for decision making.



Selection of quantitative methods for decision-making under uncertainty

Source: Ranger et al., 2010.

A similar framework was advanced by Frontier Economics (2013).



Framework for gathering data and selecting appraisal methodology

Source: Frontier Economics, 2013.

A more recent analysis (Watkiss et al., 2014: ECONADAPT, 2015) considered the applicability. This found that these applications show there are no hard-or-fast rules on which tool to use when. It is clear, however, that certain tools lend themselves more to specific contexts or sectors. The type of adaptation problem (and objective) will therefore shape the choice. Importantly, none of these tools is universally applicable to all adaptation problems and they each have particular strengths for certain types of decisions and/or applications.

Policy-level assessments are more likely to make use of the established tools that provide a framework for more aggregated analysis, although iterative risk frameworks and robust decision making also have high potential for programme/sector analysis (though they are more proven at the project level). At the project scale, tool selection will be influenced by data availability and the level of uncertainty. Several of more economic focused approaches (real options and portfolio theory) require probabilistic inputs, which is challenging for future climate projections, and they also require quantitative inputs.

The application or adaptation problem also determines the suitability of the decision tool. For example, for analysis that is focused on current climate variability (the adaptation deficit), existing decision support tools can be used, including CBA. For the analysis of short-term decisions with long life-times and longer-term challenges, a greater focus on new decision support tools is warranted. RDM has broad application for current and future time periods. When investments are nearer term (especially high upfront capital irreversible investments), and where there is an existing adaptation deficit, ROA is a potentially useful tool, whereas for long-term applications in conditions of a low current adaptation deficit, IRM may be more applicable. Importantly while the tools are presented individually, they are not mutually exclusive.

Attributes and Application of Decision Support Methods for Adaptation

Decision-Support Tool	Strengths	Challenges	Applicability	Potential use
Cost-Benefit Analysis	Well known and widely applied.	Valuation of non-market sectors / non-technical options. Uncertainty limited to probabilistic risks / sensitivity testing.	Most useful when climate risk probabilities known and sensitivity small.	To identify low and no regret options (short-term) in market sectors. As a decision support tool within ICRM
Cost-Effectiveness Analysis	Analysis of benefits in non-monetary terms.	Single headline metric difficult to identify and less suitable for complex or cross-sectoral risks. Low consideration of uncertainty	As above, but for non-monetary sectors (e.g. ecosystems) and where social objective (e.g. acceptable risks of flooding).	As above, but for market and non-market sectors.
Multi-Criteria Analysis	Analysis of costs and benefits in non-monetary terms.	Relies on expert judgement or stakeholders, and is often subjective, including analysis of uncertainty.	Where mix of quantitative and qualitative data. Can include uncertainty performance as a criteria	As above, but also use for scoping options (policy level). Can complement other tools and capture qualitative aspects.
Iterative Risk Assessment Frameworks	Iterative analysis, monitoring, evaluation and learning.	Challenging when multiple risks acting together and thresholds are not always easy to identify.	Useful where long-term and uncertain challenges, especially when clear risk thresholds.	For appraisal over medium-long-term. Also applicable as a framework at policy level.
Real Options Analysis	Value of flexibility, information.	Requires economic valuation (see CBA), probabilities and clear decision points. .	Large irreversible decisions, where information on climate risk probabilities.	Economic analysis of major capital investment decisions. Analysis of flexibility within major projects.
Robust Decision Making	Robustness rather than optimisation.	High computational analysis (formal) and large number of runs.	When large uncertainty. Can use a mix of quantitative and qualitative information.	Identifying low and no regret options and robust decisions for investments with long life-times.
Portfolio Analysis	Analysis of portfolios rather than individual options	Requires economic data and probabilities. Issues of inter-dependence.	When number of complementary adaptation actions and good information.	Project based analysis of future combinations. Designing portfolio mixes as part of iterative pathways.

Source: ECONADAPT, 2015.

It is worth noting that the differences between the tools are not limited to data and capacity constraints but may have a material impact on the order of prioritisation of adaptation options. Klijn et. al. (2014) demonstrates that applying RDM results in a different order from CBA, and CBA produces a different order from CEA.

However, a key finding is that all the new methods are resource intensive and technically complex. Indeed, this constrains their formal application to large investment decisions or major risks, i.e. priority projects for adaptation or specific adaptation projects, rather than mainstreaming. These issues are likely to limit future application in the mainstreaming context. These issues are likely to limit future application in the mainstreaming context, especially in Africa (though experience has also found this is difficult in the UK, as shown by early

implementation experience of real options analysis guidance (HMT, 2008; Mullan, personal communication).

To date they have been used to support non-mainstreamed adaptation activities/projects, but the translation into sectoral contexts, with analysts who – for example - may not have extensive knowledge of climate projections and uncertainty is likely to be difficult.

A critical question is therefore whether the concepts in these detailed tools can be used in 'light-touch' approaches that capture their conceptual aspects, while maintaining a degree of economic rigour, both at policy and project level. This would allow a wider application in qualitative or semi-quantitative analysis. This could include the broad use of decision tree structures from ROA, the concepts of robustness testing from RDM, the shift towards portfolios of options from PA, and the focus on evaluation and learning from IRM for long-term strategies. There has been some early progress advancing these types of light-touch applications, e.g. Hallegatte et al. (2012); Ranger et al (2013). However, as yet, there is nothing that seems suitable in balancing the trade-off between quantitative analysis and pragmatic application and this remains a priority for development.

Discussion

While there is a growing literature on the economics of adaptation in Africa, much of the available evidence is not so relevant for this study, either because it focuses on addressing early adaptation deficits, or it applies a science-first impact-assessment framework.

There are, however, a wide set of studies that demonstrate the consideration of uncertainty in adaptation decision support which are relevant, and these do include some examples for Africa. However, these are complex to apply, and require capacity, time and resource, which is likely to limit their application. A focus for the study is therefore to investigate 'light-touch' approaches that capture their conceptual aspects, while maintaining a degree of economic rigour, both at policy and project level.

TASK 3: BARRIERS TO LONG-TERM DECISIONS

The aim of this task is to consider the academic and grey literature on the barriers to long-term decision making, including behavioural sciences, political economy and risk perception.

Three activities have been undertaken. First, the study has undertaken a review of the literature on the barriers to adaptation. Second, a more detailed review has been advanced in relation to behavioural economics. Finally, the study has drawn up an initial table of how the barriers might affect the medium to long-term adaptation decisions identified in previous sections.

Literature Review on the Barriers to adaptation

The IPCC (2001a) defines adaptation as "the process of adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits beneficial opportunities". This definition implicitly assumes effectiveness. By contrast, UNDP defines adaptation as "a process by which individuals, communities and countries *seek* to cope with the consequences of climate change" (UNDP, 2005); and Moser and Ekstrom (2010) explicitly highlight that adaptation may or may not succeed in moderating harm or exploiting beneficial opportunities. In 2007, the AR4 Summary for Policymakers of Working Group II concluded that indeed there are "formidable environmental, economic, informational, social, attitudinal and behavioural barriers to the implementation of adaptation" (IPCC, 2007a, p. 19). Barriers can limit the range of available adaptation options and create the potential for residual damages for actors, species, or ecosystems.

This literature review will focus on the barriers that constrain human and natural systems' adaptation. It will start by providing some conceptual clarifications, then it will summarise the main findings of three strands of literature on adaptation barriers using three different analytical lenses: economic, social and institutional. With the latter two strands of literature we include a particular focus on insights from (1) behavioural economics and (2) political economy.

Barriers to climate change adaptation – conceptual clarifications

Adaptation barriers or *constraints* (the terms are frequently used as synonyms) refer to factors that make it harder to plan and implement adaptation actions. Oberlack and Eisenack (2012) present five ways in which barriers may impede the adaptation process:

1. by constraining the available means for adaptation;
2. by hampering the use of available means;
3. by increasing the cost of adaptation, including transaction costs;
4. by reducing the incentives for adaptation;
5. by increasing the incentives for maladaptation.

Adger et al. (2009) emphasise that some barriers are neither absolute nor insurmountable, but rather socially constructed, subjective and mutable, as they depend on the underlying goals and values of different decision-makers across different scales and agencies (e.g. national vs. local decision-makers). Goals differ within a sector, a society, between nation states, and between different generations; and the choice between co-existing goals is taken by institutions of collective response based on the underlying values of society.

Barriers to adaptation also vary depending on the time horizon. Factors that might represent barriers or limits *here and now* may be overcome in the future thanks to R&D, changes in risk attitude, changes in rules or funding arrangements, communication and awareness raising, etc. (see Park et al., 2012; Adger et al., 2013).

The focus of this review is on barriers to both *planned* and *autonomous* adaptation. Carter et al. (1994) define *autonomous* adaptation as ”natural or spontaneous adjustments in the face of a changing climate”. From the perspective of public policy, this tends to include adaptation actions taken by private agents without policy stimulus, for example farmers switching crops. *Planned* adaptation is seen most generally as the result of a deliberate decision, based on the awareness that conditions might change or have changed and that action is required to achieve a desired state. FankhauserFrom the perspective of public policy, planned adaptation tends to be synonymous with government intervention.

Planned adaptation can be either reactive or anticipatory. Anticipatory and reactive adaptation face different barriers since they are generally undertaken under different circumstances and using a different set of information. For example, for public authorities, barriers to anticipatory adaptation (e.g. uncertainty and budgetary constraints) may be set aside/overcome in the event of an extreme climatic shock (e.g. floods), following which climatic impacts become visible and quantifiable (uncertainty is partly unfolded) and those affected exert pressure on the government to intervene. Moreover, reactive measures such as emergency relief can be deliberately used to boost governments’ chances of being re-elected (Gawel et al, 2012).

In the adaptation literature, ‘good’, ‘successful’ or ‘appropriate’ adaptation has often been defined in the context of welfare economic theory and its underlying normative principles. According to this framework, barriers to efficient adaptation broadly correspond to market failures, or those factors that prevent the private sector from delivering socially efficient adaptation, and therefore justify government intervention. Successful adaptation actions are those that minimise the combined total of residual damages and costs of adaptation (see Fankhauser et al. 1999; Cimato and Mullan, 2010), with suitable adjustment where appropriate for distributional weighting across time and space, and barriers are those factors that hamper cost minimisation.

However, it has been argued that the normative framework underpinning standard welfare economic theory, centred as it is on the market-government dichotomy and on assumptions of rational, efficient and fair decision making, may not describe real-world decision-making and overlook a wider range of factors affecting adaptation. Many analytical lenses have been used in the literature to describe barriers to good or successful adaptation. This literature review will describe the main contributions of the different strands of the literature on adaptation barriers.

In the following section, we will go through the main barriers to climate change adaptation. They are grouped into the following categories: deep uncertainty; barriers to economic efficiency; social, behavioural and biological barriers, and; institutional barriers. These categories help describe the adaptation behaviour of the relevant decision-makers: individuals, businesses, government institutions, and the environment.

Uncertainty – a common barrier to all decision-makers

One common challenge to all decision-makers that represents a barrier to successful adaptation is *uncertainty* around future climate scenarios and their impacts. The future climate will depend partly on the future emissions trajectory, but other aspects of the climate system will also influence it. Uncertainties can arise from limitations in knowledge (e.g., cloud physics), from randomness (e.g., due to the chaotic nature of the climate system), and also from human actions (e.g., future greenhouse gas emissions, population, economic growth and development). The existence of tipping points, feedback mechanisms and limitations of existing models means that there is a wide range of possible future climatic scenarios. There has been considerable progress in our understanding of the climate system, but there will always be an inherent element of uncertainty about any climate scenario, about its impact on society and the environment and the likelihood that it will occur.

"Deep uncertainty" is defined as "the condition in which analysts do not know or the parties to a decision cannot agree upon (1) the appropriate models to describe interactions among a system's variables, (2) the probability distributions to represent uncertainty about key parameters in the models, and/or (3) how to value the desirability of alternative outcomes" (Walker et al., 2013; Lempert et al., 2003). This implies that one can (incompletely) enumerate multiple possibilities for the system model, the probability distributions, and sets of values, without being able or willing to rank order the possibilities in terms of how likely or plausible they are judged to be (Kwakkel et al., 2010).

Deep uncertainty can represent a barrier to decision making in adaptation insofar as it makes adaptation planning more difficult. Ultimately, it might prevent agents from taking decisions, or make them choose to postpone adaptation. It may also make them opt for ineffective adaptation, or maladaptation (Hall et al., 2007). Deep uncertainty require agents to use complex climatic data and make assumptions regarding costs and benefits estimation, the choice of discount rate, risk preferences, and deal with issues of scale and aggregation. Several models for decision making under deep uncertainty have been developed, each with its advantages and limitations. The complexity of these models may itself represent a barrier to adaptation decisions.

Barriers to economic efficiency: the welfare economic framework

The analytical framework of welfare economic theory rests on the assumption that decision-makers are able to take decisions that maximise their welfare or utility; and that, under certain conditions, the market is able to lead to an efficient provision of goods and services. There are several factors that prevent the market from autonomously providing and coordinating the appropriate level of adaptation and that therefore lead to an inefficient allocation of resources. Fankhauser

The following market failures represent a barrier to adaptation:

<u>Imperfect information</u> about climate impacts refers to the lack of information on future climate scenarios, but also on the adaptation options available to decision-makers and their costs and benefits.

There are at least two ways in which imperfect information can lead the market for climate adaptation to fail. The first is that information about future climate change is often a public good, which will be underprovided by private actors that cannot capture the full social benefit of generating the information through, for example, computer modelling of future climate. The second is that, if different agents in the economy hold different amounts of information (i.e. if there is an information asymmetry), then inefficiencies can arise, such as adverse selection and moral hazard. Both of these are well known phenomena in the insurance industry: under adverse selection, the insurer's inability to differentiate between 'good' risks and 'bad' risks makes it vulnerable to being adversely selected against by bad risks, in other words customers whose probability of making a claim is relatively high. Under moral hazard, taking out insurance makes people less likely to take actions to insure or protect themselves than they otherwise would be (see Burby et al.,1991; Laffont, 1995; Cimato and Mullan, 2010).

Externalities and Public Goods. Acting rationally in their own interest, individuals will base their adaptation decisions on private costs and benefits. However, some adaptive actions might have the nature of public or quasi-public goods (local, national or local), so individual action will be socially inefficient (Cimato and Mullan, 2010). This is the case with transboundary waters, when increased irrigation in one country creates water scarcity downstream (Goulden et al., 2009). Examples of adaptation investments with the characteristics of public goods[3] include investment in certain kinds of infrastructure (e.g., flood defences), R&D programmes (where these generate spillovers that cannot be fully reaped by private agents), monitoring and warning systems, and protection of ecosystems (as well as climate forecasts, as mentioned above).

Misaligned incentives and missing markets. In the management of physical assets, a typical example of this barrier is the uneven split of adaptation costs and benefits between property owners and tenants, which results in little or no incentive to invest to make the property more resilient (Cimato and Mullan, 2010).

Market structure. The market structures in which businesses operate (monopoly, oligopoly or perfect competition) shape the incentives and affect the investment decisions on climate change adaptation. Lee et al. (2010) describe the 'competition effect' and how different market conditions can affect the incentives for businesses to adapt: a monopolist is likely to put in the highest efforts to adapt, since it directly recovers its profit loss under climate change; whereas in an oligopoly, competition and strategic interaction may lower additional profit potential for businesses, which translates into less incentive to adapt. Economic sectors vulnerable to climate change such as energy and water are often populated by state-owned monopolies or by regulated natural monopolies and oligopolies.

Market distortions. This can be an economic barrier, as well as a policy barrier, and describes how existing market distortions – often pursued for good reasons by governments, such as revenue raising or to achieve distributional fairness – affect incentives to adapt. As described by Fankhauser et al. (1999), when market signals are distorted, people may under- or over-adapt. For example, if, due to market distortions (e.g. price or income subsidies), crop yield changes do not translate into income changes, farmers may not adjust to a changing climate by varying the

[3] Pure public goods are characterized by non-excludability, that is, if a public good is made available to one consumer then it is effectively made available to everyone; and non-rivalry in consumption, that is, the consumption of the good by one person does not prevent someone else from using or consuming that good.

varieties of crops they plant. Fixed allocations of water resources may lead to a similar lack of incentives to adapt (Fankhauser et al., 1999). Similarly, Lee et al. (2010) show that if land use is inflexible, in a perfectly competitive market farmers will be less likely to adapt due to their inability to expand business along with their adaptation investment and little potential to reap additional profit.

Finally, *financial barriers* constrain what individuals, the market and governments can efficiently achieve. This is not a market failure *per se*, but rather limits what is feasible. According to the IPCC 5th Assessment Report, existing global estimates of the costs of adaptation in developing countries range from US$70 billion to US$100 billion a year globally by 2050. UNEP (2014) suggest that these values are likely to be a significant underestimate, particularly in the period after 2030; and that the costs of adaptation are likely two-to-three times higher than the estimates reported thus far, and plausibly much higher than this towards 2050. However, it is reported that the amount of public finance committed to activities with explicit adaptation objectives ranged from US$23 billion to US$26 billion in 2012–2013, of which 90 per cent was invested in developing countries (UNEP, 2014)[4].

Individuals will adapt within their capacities as defined by their informational, budgetary, institutional, technological and other constraints and opportunities (Oberlack and Neumarker, 2011; Stern, 2006; Kuch/Gigli, 2007; Osberghaus et al., 2010; Hallegatte et al., 2011). Empirical evidence shows that lack of credit, and lack of information and knowledge, represent a major barrier to climate adaptation for farmers in Africa (IFPRI, 2007; De-Graft Acqua and Onumah, 2011; Debalke, 2011); and that households' wealth increases the likelihood of climate change awareness and adaptation (Yesuf et al., 2008). Deressa (2008) observed that the age of the household head, wealth, social capital and agro-ecological settings have a significant impact on farmers perception of climate change.

Social, biophysical and behavioural barriers

Empirical evidence shows that individuals and institutions such as firms do not always respect the simple axioms of rational choice. Along with market failures, other barriers to adaptation emerge from a broader consideration of how social and behavioural factors affect decision-making, and of biophysical constraints to adaptation in the natural world.

Social values frame how societies develop rules and institutions to govern risk, and to manage social change and the allocation of scarce resources (Ostrom 2005), and therefore can hamper or support adaptation. Adger et al. (2009) describe barriers that are endogenous and emerge from 'inside' society. Within a society/sector/firm, divergent goals for adaptation emerge, in part, from different attitudes to risk (risk-takers versus the risk-averse), disposition (a progressive versus conservative ethos) and different expectations of the adaptive capacity of future generations (optimistic versus pessimistic). Berkhout et al. (2006) showed how different firms operating in the same sector (house construction) adopted different adaptation strategies to deal with the same risk of increasing river flooding.

[4] These estimates are a combination of Official Development Assistance (ODA) and non-ODA finance by governments; Climate Funds earmarked for adaptation; and commitments by Development Finance Institutions. The latter contributed US$22 billion, or 88 per cent, of the total; bilateral adaptation- related aid commitments by government members of the Organization for Economic Co-operation and Development (OECD) provided 9 per cent; the remaining 2 per cent came from adaptation dedicated Climate Funds (UNDP, 2004).

Social and cultural factors influence perceptions of risk, what adaptation options are considered useful and by whom, as well as the distribution of vulnerability and adaptive capacity among different elements of society (Grothmann and Patt, 2005; Weber, 2006; Patt and Schröter, 2008; Adger et al., 2009; Kuruppu, 2009; O'Brien, 2009; Nielsen and Reenberg, 2010; Wolf and Moser, 2011; Wolf et al., 2013).

Ethical, cultural, risk and knowledge considerations shape individuals' and societies' risk perception, the importance they place on scientific findings as opposed to indigenous knowledge, and the value they give to places and traditions (see Adger et. al, 2009). All these elements influence how they respond to climate change. Maddison (2007), for example, highlights the importance of perception and experience in triggering adaptation planning by farmers in Africa, and how transitional costs might indeed arise from mis-perception of climatic changes. The psychological literature shows that individuals tend to respond most to issues, risks or concerns they consider as immediately and personally relevant (Moser and Dilling 2004; Paton et al. 2001), the so-called 'availability heuristic'.

People respond not just to the risk itself, but also to other people's responses to risk (Kasperson et. al, 2003). Dawnay et al. (2005) argue that people tend to observe the behaviour of others and, if successful, imitate it, especially under ambiguity, in crises, and when others are seen as experts. In Africa farmers are more inclined to adapt when they are able to observe neighbouring villages' behaviour, but less inclined to learn from people belonging to different ethnic groups (Maddison, 2007).

Strongly held beliefs and cultural practices can greatly influence the way people perceive climate change and thereby their subsequent adaptation strategies (Jones and Boyd, 2011; Stafford-Smith et al., 2011; Adger et al., 2012). For example, Nielsen and Reenberg (2010) report that in northern Burkina Faso cultural practices prevented one ethnic group—the Fulbe—from embracing livelihood-diversification strategies such as development work, labour migration and gardening to reduce their vulnerability to droughts; whereas another group—the Rimaiibe—have used such strategies. Similarly, Rademacher et al. (2012) observed that social and cultural norms constrain female migration compared to male migration in the Nadowli district of Ghana, showing that gender may indeed represent a barrier.

Indigenous knowledge may also play a role by supporting or preventing good adaptation. Cultural preferences for traditional versus more formal, scientific forms of knowledge influence what types of adaptation options are considered legitimate (Jones and Boyd, 2011). Case studies from multiple developing countries report that some actors view natural phenomena as being controlled by God, supernatural forces, or ancestral spirits, which are not amenable to human management (Grotham et al., 2013; Mustelin et al., 2010; Kuruppu and Liverman, 2011; Artur and Hilhorst, 2012).

Social barriers also include the social factors that affect the adaptive capacity of individuals and communities. Gender, age, education, access to infrastructure and finance, and access to markets are all element that affect the adaptive capacity (or lack of it) of individuals and social systems.

Biological and physical constraints represent barriers to the adaptation of human and natural species. They refer to tolerance limits of individuals and the natural environment to climate change and extremes. The ability of natural systems to adapt may be hampered by the rate of

climate change exceeding the system's ability to respond, but also by the existence of other stresses, and the effects of human activity (Klein et al., 2014; Cimato and Mullan, 2010). Furthermore, physical constraints such as the lack of corridors for species migration or soil/water scarcity might constrain the ability of the natural environment and humans to adapt too. Additional research is needed to clarify the capacity of species and communities to migrate in response to a changing climate (Klein et al., 2014).

Insights from behavioural economics/science

There is by now a huge literature on behavioural economics, although, by its very nature, it does not offer a unified theory. There are two particularly common ideas prevalent in this literature: (a) individuals face cognitive limitations that can sometimes lead to 'irrational' decisions; and (b) preferences are formed in a social context where norms, perceptions of fairness and other factors influence decision-making.

As far as long-term decisions that affect climate vulnerability are concerned, at a high level of abstraction, the following key insights from behavioural economics are central.

Hyperbolic discounting

Hyperbolic discounting refers to the idea that individuals do not discount the future at a constant rate, as typically assumed in neoclassical economics, but rather do so at a declining rate that can be approximated by, for instance, a hyperbolic function.

This means that a larger discount rate is applied when comparing immediate consumption with consumption delayed by *t* periods, relative to when the comparison is between consumption delayed by *k* periods with consumption delayed by *k+t* periods. For instance an individual faced with a choice between £100 today or £110 tomorrow might well take £100 today; but if offered £100 in 30 days' time or £110 in 31 days' time might well take £110 in 31 days' time. Empirically there may be a particularly striking 'immediacy effect', whereby the discount rate applied in the initial months or years is very high (Prelec & Loewenstein, 1991).

Hyperbolic discounting has rather complicated implications. But to begin with it is important not to confuse this phenomenon, whereby individuals in effect apply a declining discount rate to their own life choices, with the accepted argument for declining discount rates in public policy and project appraisal (HM Treasury, 2003), which is based on constant preferences, but uncertainty about future growth prospects (Gollier, 2002; Weitzman, 2001).

Hyperbolic discounting suggests that people will be relatively patient when engaged in long-term planning – possibly *more* patient than typically assumed – but certainly *less* patient in the short term. This raises the possibility that people are vulnerable to being time-inconsistent: they make a plan to undertake, at some point in the future, some activity that will have immediate costs (once undertaken) in return for future benefits (they put this off until their per-period discount rate becomes low enough), but, when the time comes to do so, they renege on their plan and postpone the activity again, because their per-period discount rate is very high.

This is linked with ideas of (a lack of) self-control and of commitment devices to overcome this, which is where many of the policy implications of hyperbolic discounting are identified. For example, in his review of the implications of behavioural economics for development,

Mullainathan (2005) points out that ROSCAs[5] might serve as a commitment device for savers in developing countries, who would otherwise lack the self-control to save money under immediate pressures for it.

He also suggests that people with apparently high discount rates may simply lack the institutions to help them exercise self-control, which means that their discount rates ought not, perhaps, to be taken on face value. More generally, if people would like to exercise self-control and make decisions with long-term pay-offs, but are prevented from doing so by their own myopic tendencies, then there may be a justification for at least 'nudging' behaviour in certain situations (so called 'libertarian paternalism'; Thaler & Sunstein, 2008).

Yet the implications of hyperbolic discounting for long-term decision-making that affects climate vulnerability do not seem to have been explored and they are rather unclear. On the one hand, if everyone exhibits these kinds of time preferences, then it is of potentially profound importance, as all decisions with long-term effects will be subject to this form of 'bias', displayed by the people charged with making them. On the other hand, it can be rather difficult to relate the experimental contexts in which insights on hyperbolic discounting have been generated with the typical decisions in focus in this project.

In particular, most insights on hyperbolic discounting have been generated in relation to individuals' lifestyles (e.g. why people find it difficult to give up smoking) rather than large infrastructure planning decisions involving potentially large numbers of individuals tasked with thinking rationally. It may be that, in infrastructure planning, the institutional discount rate – the discount rate effectively applied by the institution tasked with making decisions (i.e. an informal concept) – is therefore constant and consistent with standard theory. To use Kahneman's (2011) framework, hyperbolic discounting might be seen as a manifestation of subconscious, 'system 1 thinking', while infrastructure planning forces conscious, 'system 2 thinking'.

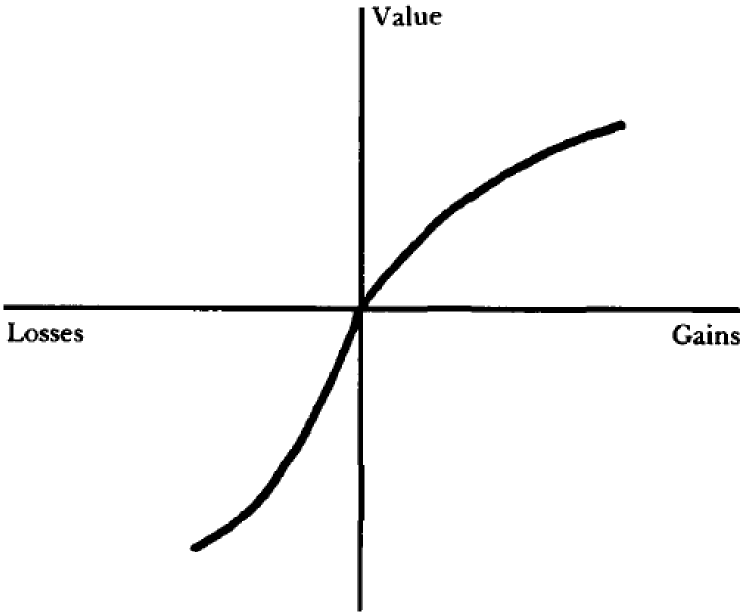
Lastly, while there is plenty of evidence from laboratory experiments for the existence of hyperbolic discounting and, as such, it has become a very well-known phenomenon, the evidence across the full gamut of relevant experimental and field studies is more mixed (Cardenas & Carpenter, 2008). It is ultimately not entirely clear that the simpler model of exponential discounting should always be rejected.

Reference dependence, loss aversion and status quo bias

Another famous insight from behavioural economics is that when people make choices, either in risky or riskless environments, their current endowment of goods – their reference point – matters. In particular, people dislike losing goods more than they like gaining goods, a phenomenon that is often known as loss aversion – particularly when it comes to risky choice – and is part of the broader Prospect Theory pioneered by Kahneman and Tversky (1979).

The effect can be represented graphically by a utility function with respect to the good in question, which is kinked at the reference point (the current endowment of that good), with the function steeper in the domain of losses than in the domain of gains.

[5] Rotating Savings and Credit Associations



There are several high-level implications of reference dependence and loss aversion for long-term decision-making that affects climate vulnerability. Like hyperbolic discounting, some of these are still vague, however.

First, it is worth noting in the context of time discounting that reference dependence and loss aversion have been proposed as one resolution to the 'equity premium puzzle' . This relates to the inability of the standard theories in the economics of risk (with uniform risk aversion, broadly speaking) to explain the large disparity between the returns on risk-free assets like treasury bonds and risky assets like stocks. It has been proposed that loss aversion makes individuals less willing to take risks and hence require higher returns on risky assets (Benartzi & Thaler, 1995). In turn, this has implications for the extent to which market returns on risky assets are relevant for public-sector discount rates, including for climate-change adaptation. In particular, it contributes to arguments that question the relevance of high rates of return on risky investments for setting public-sector discount rates, suggesting that lower rates of return on risk-free investments are more relevant.

Second, it is possible to use the concept of loss aversion to make a much broader point about the political economy of decisions that create winners and losers in society. Loss aversion is one interpretation of why it can be especially difficult to implement reforms and policy changes that constitute efficiency gains overall, but that transfer resources from one interested group to another, since the losses will be valued even more than in the standard model (Mullainathan, 2005). This suggests it may be better to design reforms that preserve the rents of incumbents. This point links with the following section that considers the more standard political-economy literature.

Third, loss aversion can be used to explain the phenomenon of status quo bias (Samuelson & Zeckhauser, 1988) as it provides an explanation for why the disadvantages of departures from the status quo loom larger than the advantages (Kahneman, Knetsch, & Thaler, 1991). Other explanations of status quo bias also exist, however, including the role of habits in decision-making. Status quo bias has obvious, if general, implications for decisions affecting climate

vulnerability, where vulnerability would be reduced by deviating from the status quo. Colloquially, status quo bias is thought to be a particular affliction of cautious public servants.

Fourth, loss aversion would increase the benefits of adaptation measures that reduce vulnerability to future climate change (and correspondingly increase the costs of related decisions that increase vulnerability), because greater value would be placed on the avoided damages.

Other issues of indirect relevance: the propensity to cooperate in social dilemmas

A general insight from the literature on experimental public goods games is that people often cooperate more than the standard conception of rational behaviour would predict. In a developing-country context, such experiments point to norms of trust and reciprocity acting as a substitute for formal institutions in managing collective goods, including environmental resources (Cardenas & Carpenter, 2008).

The question, which seems relevant in relation to social protection schemes and insurance, is whether the building of new, formal institutions *crowds out* existing social preferences that aid cooperation. Unfortunately the evidence, at least from experiments in behavioural economics, is unclear.

Institutional barriers

The welfare-economic rationale for policy intervention is based on the existence of market failures, and does not preclude doing so on the basis of distributional inequities, but it implicitly assumes an effective (and fair) government response. However, this is not a given and various literatures examine the possibilities for institutional barriers. These notably include institutional analysis and the economic literature on political economy.

Policy failures or barriers occur when conflicting policy objectives co-exist that can lead to maladaptation or lack of clarity (Frontier Economics, 2013). For example, urban development plans may be undertaken without taking into account the impact on citizens' vulnerability. These barriers occur when the current structure of institutions and regulatory policies is poorly aligned to achieve adaptation objectives (Craig, 2010; Spies, 2010; Stillwell et al., 2010; Stuart-Hill and Schulze, 2011; Eisenack and Stecker; 2012; Huntjens et al., 2012; Herrfahrdt-Pähle, 2013). Policy failure can also arise in case the production of scientific and technical information lacks salience, credibility, or legitimacy in the eyes of critical players at different levels (Cash et al., 2003). Other barriers constraining the capacity of institutions to perform effectively are the lack of information and or professional skills, but also the lack of a clear mandate (see Klein et al. 2014).

In addition to policy failures, *governance failures* or barriers might occur. If one of the roles of government is to resolve conflicts between agents to engender collective action, then the importance of governance in adaptation decisions becomes increasingly important (Cash et al., 2006). These barriers refer to ineffective institutional decision-making processes. Adaptation typically requires multiple actors and institutions with different objectives, jurisdictional authority and levels of power and resources. Overlapping mandates and responsibilities of different authorities may occur. Barriers arise from diversity in responsibility and co-ordination failure where sectors are fragmented and many parties are involved in adaptation actions

(Frontier Economics, 2013), they operate in silos and/or compete for resources and policy control (Lockwood, 2006).

Lehmann et al (2012) argue that how well an institutional framework is suited to promote adaptation planning depends on the horizontal and vertical integration of decision-making. Vertical integration occurs between local, regional and national decision levels; whereas horizontal integration may occur within public administration and beyond (through participation of businesses, science, NGOs and civil society in the decision making process). Based on an empirical analysis, Lehman et al. (2012) report on the barriers faced by local municipalities in four cities, namely Lima, Santiago, Berlin and Sangerhausen. The results show that, as well as the problem of short-termism inculcated by electoral cycles and developed below, the lack of a clear mandate and responsibility, of coordination and resources, and low levels of inter-organisational cooperation all hinder effective adaptation planning.

Mainstreaming adaptation into existing administrative tasks and activities is expected to increase the incentives for adaptation planning by facilitating the identification of links to other (sectoral) policy objectives with a possibly higher political priority and potential co-benefits (Measham et al., 2011; UNDP/UNEP, 2011); and reduce the costs of adaptation planning (see Fussel, 2007; Fussel and Klein, 2004). However, effective mainstreaming requires a lead organisation to ensure coordination across sectors (Hunt and Watkiss, 2011).

Setz et al. (2008) refer to the lack of institutional memory and inter-institutional coordination as barriers to project design, approval and even access to international funds and aid for adaptation. The authors add that the overlapping mandates of government entities tend to create conflicts and slow adaptive responses, for example in case of extreme events. Lengthy bureaucratic processes and lack of transparency is an impediment to fiscal planning and may access to finance, which is particularly relevant for African countries.

Finally, the lack of universally applicable indicators for adaptation benefits means that monitoring and evaluating adaptation outcomes might be challenging. Indicators are meant to inform decision-makers about the effectiveness of adaptation actions, contribute to social learning about good practices, holding agents accountable for their decisions, and communicating outcomes (Lamhauge et al., 2012). As assessments of adaptation effectiveness they can be meant to inform the prioritisation of adaptation funds (Stadelmann et al. 2011). Poorly designed indicators may prevent funding allocation by donors for example. In this respect, they can hinder adaptation.

Insights from political economy

The political economy literature is large and varied. We can follow Besley's (2006) authoritative literature review, which sees its various insights coalescing around the notion of *government failure*. According to Besley, government failure captures the idea that "there are systematic reasons why government fails to deliver the kind of service to its citizens that would be ideal" (p45).

But what constitutes the ideal service? One definition of government failure due to Besley and Coate (1997) draws from the theory of market failure: a government fails when its actions prevent the economy from attaining Pareto efficiency, i.e. it would in theory be possible to reallocate resources such that at least one person is better off without anyone being worse off.

However, just like the theory of market failure, we could make the observation that Pareto efficiency is a relatively undemanding criterion, as there could be many Pareto efficient allocations, which are undesirable from the point of view of distributional fairness, for instance they concentrate too much wealth among the rich and powerful. Therefore governments might also fail on fairness grounds.

Two other features that may be identified of the political economy literature as a whole are that (1) it is mainly based on the assumption of rational individual behaviour, in contrast to behavioural economics, and (2) it is often developed in the context of representative democracy (Persson & Tabellini, 2000), which may be particular relevant in advanced economies but have varying degrees of purchase in developing economies.

The insights of the political economy literature apply to government in the broadest sense, i.e. the list of government failures enumerated below applies in principle to many areas of policy-making. The question is whether they apply with greater or lesser force to climate adaptation. There is some reason to believe that they may apply with greater force, since climate adaptation involves particularly large uncertainties (a shortage of information), and can involve very long-run benefits that raise questions of the political representation of future generations and government commitment problems (time inconsistency). On the other hand, relative to other policy decisions, some kinds of adaptation decision may involve fewer vested interests, and in some cases government failures like corruption may actually bias policy-making in favour of large infrastructure investments that could be resilient to future climate.

What then are the sources of government failure that could be relevant to decisions that affect long-term climate vulnerability?

Imperfect information

A long tradition in political economy, including notably the work of Hayek, argues that imperfect information on the consequences of government decisions puts a limit on the capabilities of state planning. There is an obvious sense in which mis-estimation of the costs and benefits of decisions will lead to government failures, relative to a situation of perfect information. This may be particularly profound in the case of climate-change adaptation, where the long-run costs and benefits of decisions are highly uncertain.

However, the most fundamental political-economy implications of imperfect information typically arise when different individuals hold different amounts of information. Ruta (2014), for example, looks at agency problems in the giving of adaptation finance from developed donor countries to developing recipient countries, which arise in part because the donor lacks perfect information about what the recipient is doing with the money, itself in part because of the difficulties of measuring the costs and benefits of adaptation measures in a context in which they are intertwined with general development.

More generally there are likely to be many agency problems in the provision of infrastructure in developing countries just as there would be indeed in developed countries.

Lobbying, corruption and rent-seeking

Another important insight from political economy is that public officials do not, or, at least, do not only, act in the public interest like a benign dictator, rather they aim to advance their own interests, sometimes described as 'opportunism' (Persson & Tabellini, 2000). Grossman and Helpman's (2001) model of lobbying portrays a government that affords some weight to the maximisation of social welfare, on the one hand, and some weight to financial contributions from lobby groups for the purposes of resourcing political campaigning, on the other hand.[6]

In these circumstances, outcomes are skewed away from what maximises social welfare towards the interests of organised and well-resourced lobby groups. Whether this is inefficient depends on the model of government failure: it is not Pareto inefficient unless there are costs to lobbying activities (over and above the transfers themselves, which are just that), but it might often be thought of as inequitable. Which special interests prevail depends in part on their ability to organise and act collectively (Olson, 1965).

While this model is most immediately applicable to political systems where there is political democracy and where it is legitimate to make financial contributions to political parties, simple models of corruption and bribery work in much the same way, in that governments auction off policies, projects and how projects are delivered to the highest bidder. Indeed, this interpretation of economic models of political influence is potentially the most relevant in many developing countries.

In principle, corruption and bribery could be employed to encourage or discourage infrastructure investment, but in practice organised and well-resourced special interests are often located amongst the beneficiaries of investment and therefore it is classically an ingredient in 'white elephant' infrastructure projects or more generally in infrastructure projects that are inefficiently designed or delivered.

A different tradition of political economy models that also assesses the effects of influence focuses on rent-seeking (Krueger, 1974; Tullock, 1967, 1980). In these models, politicians do not receive payments from special interests, nonetheless these interests have an incentive to try to influence political decisions and doing so has an opportunity cost in terms of productive labour. Politicians in these models are typically rent-seeking rather than office-seeking. Again, whether rent-seeking leads to government failure is complicated. In and of itself it is costly, but the outcome might sometimes provide benefits in excess of costs.

Also belonging to this broad theme is research on the incentives of bureaucrats, as opposed to politicians. Niskanen (1971) proposed the budget-maximising model of bureaucratic behaviour, which suggests that self-interested bureaucrats aim to maximise the budgets of their agencies in order to increase their power and wealth, even if the politicians for whom they act as agent have the public interest in mind. That they enjoy this possibility is due to the type of informational asymmetry mentioned above: agencies are presumed to better know their costs and benefits than the politicians who rely on them.

Quality of decision-making

The aforementioned models do not take into account are the intrinsic qualities of political leaders and policy-makers, aside from their tendency to be self-interested. However, some

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[6] Other means of lobbying exist, such as information.

policy-makers may produce 'better projects' than others, in a general sense, or else they are better at carrying out their citizen's wishes.

This is a simple source of government failure in the sense that improvements could be obtained by improving the quality of policy-makers. In contrast to models of influence, corruption and rent-seeking, this argument, broadly speaking, relates to the human capital attainment of policy-makers.

Political failures in democracies

A basic source of political failure in democracies can arise under simple majority voting and is best understood as follows: simple majority voting merely counts the number of voters in favour of, or against, a particular policy change but ignores the *intensity of people's preferences*. If, for example, a majority of people stand to gain a small amount and yet a minority of people stand to lose a great deal, then majority voting will favour the former over the latter, even though aggregation of preferences in the standard economic way (even without considerations of loss aversion) would tend to work against this. Note this effect stands in contrast to what might usually be expected to follow from special-interest capture, discussed above under point 2.

Another form of political failure can arise from so-called 'log-rolling', i.e. the trading of favours between politicians in order that each gets the policies passed that s/he wants (this is sometimes specifically called 'distributive log-rolling' and the original idea is from Buchanan & Tullock, 1962). Such situations can – at times, i.e. not inevitably – lead to too many public projects being implemented.

In the context of long-term decision-making that affects climate vulnerability, if it can be argued that too little weight is being placed on the interests of future generations who lack the ability to vote – a not uncontroversial claim that is at the centre of the discounting debate – then this is also a political failure that could lead to insufficient adaptation to future climate change. Folke et al. (1998) and Young (2003) discuss the barriers to sustainable resource management stemming from the conflict between short electoral cycles and long-term planning needs.

Commitment and time inconsistency

The work of Kydland and Prescott (1977) focused attention on government failures, which can arise from the inability of a politician or policy-maker to commit ahead of time to a particular course of action. This is because it can be rational for a policy-maker to later change course, even one that is benevolent and is not subject to the need to get re-elected.

In a simple model of this kind of time-inconsistency in public policy, a government that is benevolent in the sense of trying to maximise social welfare must choose whether to implement a policy today and/or tomorrow. Society receives benefits and costs from the policy, as well as being able to make private investments today that pay off tomorrow. The model can be set up in such a way that, even though it would be best for society if the government implemented the policy tomorrow and citizens made private investments today, the government would choose not to implement the policy tomorrow upon knowing that citizens have made the investment today. With rational expectations, citizens don't then make the investment.

In this simple example, the only thing linking today and tomorrow is investment, but other political-economy models introduce policy and political linkages. The former type of linkage makes the success of the policy tomorrow dependent on whether it is implemented today, while the latter type of linkage introduces political survival from today to tomorrow as a consideration. Policy linkages have been used to explain why politicians make strategic choices to constrain the actions of their successors. The desire to survive in political office, on the other hand, can lead politicians to postpone or bring forward policies depending on the situation and this can lead to a deviation from what is efficient or equitable.

Mapping of Barriers to Decisions

The sections above highlight the potential barriers to adaptation. However, this provides a theoretical perspective. A key issue for the current study is to translate these issues into a more practical setting, and then look at potential solutions.

To advance this analysis, the study has mapped the potential barriers identified above to the priority areas we have identified for medium to long-term adaptation decisions. This is shown below.

The table presents the main barriers to climate change adaptation – focusing on spatial planning, service and infrastructure delivery - and proposes some possible solutions.

Review of barriers to adaptation planning and decision-making

Decisions	**Market failures**	**Policy Failures**	**Governance failures**	**Social and Behavioural barriers**	***Examples of Solutions***
Early decisions that can lock-in vulnerability					
Urban and Spatial Planning	Information failure Externalities Club goods Market distortions (e.g. price of houses on flood prone areas does not reflect risk) Misaligned incentives for people living in urban areas (e.g. tenants vs. owners)	Regulatory barriers stemming from multiple frameworks applying to various sectors (land use, housing, transportation, public facilities and services etc.) Limited coverage of or no mandatory action within legislation and regulations Conflicting policies/priorities (e.g. pressure for urban development/housing counteract with adaptation goals/reducing vulnerability) Lack of clear roles and responsibilities of actors involved in adaptation Spatial/Urban plans are poorly enforced Limited adaptation for existing buildings/assets	Institutions with a role to play in climate change adaptation are poorly integrated, both between sectors and across spatial scales Range of decision makers involved (developers, building companies, insurance companies, property owners and occupants) who base their decisions on different time scales and goals Lack of clarity and accountability mechanisms for adaptation decisions Some adaptations with the characteristics of club goods requiring high coordination and joint actions. Highly bureaucratic processes make decision making lengthy	Cognitive biases of policy makers-urban planners, as well as urban citizens Limited adaptive capacity of planning authorities (time, money and human resources) Limited adaptive capacity of urban inhabitants (access to finance - including insurance, information) Inertia and procrastination of both planners and urban inhabitants Demographic and socio-economic phenomena (e.g. migration, population growth) Social norms (e.g. social capital)	Review and harmonise regulatory frameworks governing urban planning Consider a cross-sector strategy for mainstreaming adaptation actions into existing urban management activities, including land use planning, transportation, water, and environmental policy. The strategy should define risks, set priorities, competences, and actions for different actors Consider establishing a lead government department playing a coordinating role Improve understanding of and information on costs and benefits of adaptive measures for the built stock in the urban environment Capacity building for planners. Consider developing guidance. Appropriate staffing of planning agencies Design information campaigns that use social norms for behaviour change e.g. by informing individuals about desirable behaviour of others, possibly by emphasizing the real statistical probability of different risks

Decisions	Market failures	Policy Failures	Governance failures	Social and Behavioural barriers	*Examples of Solutions*
Integrated Water Resource Plans	Information failure Market distortions and externalities (e.g. water pricing) Different opportunity cost of water to different users	Conflicting policies/priorities (agriculture, energy, domestic water use, recreation) Lack of integrated regulatory frameworks applying to different water uses (agriculture, energy, urban planning) Lack of clear roles and responsibilities of actors involved in planning and adaptation	Wide range of stakeholders involved in water management and use, plus multiple uses (irrigation, energy, domestic consumption) contribute to complex decision-making process. Different actors/agencies likely to operate in silos Coordination on vast spatial scale required (e.g. upstream/downstream)	Cognitive biases of policy makers, planners, as well as urban citizens Limited adaptive capacity of planning authorities (time, money and human resources) Limited adaptive capacity of water users (e.g. access to finance, information) Inertia and procrastination of both planners and water users Social/customary beliefs and water management practices	Improve understanding of and information on costs and benefits of adaptive measures Reviewing of regulatory frameworks to ensure policy coherence Consider a cross-sector strategy for mainstreaming adaptation actions into existing water management activities, including land use planning, agriculture, energy, and environmental policy. The strategy should define risks, set priorities, competences, and actions for different actors Consider establishing a lead department playing a coordinating role on IWRM Capacity building for planners. Consider developing guidance. Communication and engagement plan to change users behaviour Introduce demand-driven solutions: low-flow appliances; more effective use of water in agricultural and industrial processes; smart meters and intelligent pipework to restrict access and reduce leakage; and metering and pricing strategies.

Decisions	Market failures	Policy Failures	Governance failures	Social and Behavioural barriers	*Examples of Solutions*
Coastal Management Planning	Information failure Missing markets (ecosystems services) Club goods/public goods	Poor integration of coastal plans and regulations into local/regional spatial plans and regulations Overlapping mandates of different agencies and government institutions Multiple regulatory frameworks applying (e.g. infrastructure, buildings, habitats and livelihoods) and poorly integrated Conflicting priorities (environmental preservation vs economic development and housing)	Wide range of stakeholders and decision makers involved (e.g. environment protection agency, local governments, local communities, local businesses, insurance companies) Poor coordination between agencies responsible for adaptation High level of coordination/local funding mechanisms required for club goods (e.g. local sea walls)	Cognitive biases of policy makers, planners, as well as local communities living in coastal areas Limited adaptive capacity of planning authorities (time, money and human resources) Limited adaptive capacity of communities (lack of info, resources) Inertia and procrastination of both planners and coasts inhabitants Limited adaptive capacity of the natural environment	Coastal management planning integrated in broader spatial management plans Harmonisation of regulatory frameworks applying to adaptation in coastal areas (tourism, housing, environment, buildings, infrastructure) Clarity around different agencies' roles and responsibility. Consider select a lead institution/agency with clear mandate Targeted communication and engagement strategies with local communities, using local social norms to change behaviour Capacity building and training for planners
Decisions	**Market failures**	**Policy Failures**	**Governance failures**	**Social and Behavioural barriers**	***Examples of Solutions***
Land Use and Agricultural Development Plans	Information failure Externalities High transaction/coordination costs Market distortions (e.g. subsidies)	Multiple regulatory frameworks (water management, agriculture, environmental regulations, spatial planning) International regulations and markets affecting domestic production and prices, i.e. incentives to adapt	Large number of decision makers (farmers) pose coordination challenges Lack of coordination between relevant government agencies (e.g. Agriculture, Forestry)	Cognitive biases of policy makers Cognitive biases of farmers Lack of adaptive capacity of farmers (info, access to technology, access to finance) Customary land tenure and land management practices Habit and taste (e.g. switching to more climate resilient crops and changing diet may be difficult)	Clarity of mandates, roles and responsibility of different agencies Removal of market distortions (e.g. subsidies) affecting adaptation decisions Alignment and harmonisation of different regulatory frameworks (on water, environment) Consider a cross-sector strategy for mainstreaming adaptation actions into existing land management activities, including land use planning, agriculture, and environmental policy. The strategy should define risks, set priorities, competences, and actions for different actors Information campaigned tailored to farmers to improve understanding of costs and benefits of adaptation measures

Decisions	Market failures	Policy Failures	Governance failures	Social and Behavioural barriers	*Examples of Solutions*
Social Protection Policy	Public Good Fiscal space	Adaptation, DRR and social protection policies and objectives not aligned/sufficiently integrated Trade off between short term (DRR, poverty alleviation) and long term needs (climate change vulnerability) Conflicting policies and regulatory frameworks (e.g. economic and social policy objectives) SP target people who are currently vulnerable – less focus on potential vulnerable people in the future Vulnerability to climate change not explicitly considered in policies	Cross cutting nature of Social Protection policies (housing, services, direct transfers) and multiple decision makers involved Overlapping mandates of different agencies – lack of coordination and working in silos Possible complexity of some mechanisms (index-based insurance schemes) or risk of heavy governance structure (social funds for community based adaptation)	Cognitive biases of policy makers Cognitive biases of beneficiaries of social protection schemes – inertia, procrastination, short-sighed decision making Lack of capacity of responsible agencies (staff, time, resources) Low adaptive capacity of recipients of social protection measures (typically the most vulnerable in society)	Clarity of link between adaptive capacity and social protection schemes – cc vulnerability explicitly addressed Consider a cross-sector strategy for mainstreaming adaptation actions into existing social protection plans and activities. The strategy should define risks, set priorities, competences, and actions for different actors Enhanced emphasis on preventive measures to increase adaptive capacity Communication strategy targeted to the poor and most vulnerable around cc risks

Early investment that exposed to future climate risks					
Decisions	**Market failures**	**Policy Failures**	**Governance failures**	**Social and Behavioural barriers**	***Examples of Solutions***
New Critical Infrastructure (e.g. public water supply, hospitals, waste-water treatment)	Information failure Public goods generating positive externalities (e.g. health), natural monopolies (e.g. energy distribution), and merit goods (e.g. water) Market distortions (e.g. water tariffs kept inefficiently low) Misaligned incentives (depending on how concession contracts are built) Limited public fiscal space	Overlapping policies/priorities and existence of trade-offs (e.g. between continuity of supply and affordability; development and vulnerability) Government agencies lacking a clear mandate on adaptation Incentives to adapt not built into PPP contracts Poorly defined responsibilities, or lack of coordination between various operators (particularly relevant due to interconnectivity between the infrastructure assets)	Multiple and complex levels of decision making involved (designers, owners, operators, users) Lengthy decision-making process Risk of policies being designed and implemented in silo by different agencies/decision makers Lack of lead agency, and lack of clear line of accountability for adaptation Risk of corruption/misuse of funds	Cognitive biases of decision makers responsible for deciding on infrastructure investment (e.g. use of complex climatic info, lack of clarity around costs and benefits of options) Perceptive biases (e.g. recent stress) Self-interest of decision makers (e.g. elections) Low adaptive capacity (e.g. no access to technology, finance, information) of different agents Inertia and procrastination preventing people from using public services and infrastructure more sustainably	Improve understanding of climatic thresholds impacting on the performance of different infrastructure Review and harmonise existing regulatory frameworks for interconnected infrastructure assets Review regulations and design standards to incorporate climate change Consider a cross-sector strategy for mainstreaming adaptation into infrastructure planning and activities. The strategy should define risks, set priorities, competences, and actions for different actors Consider selecting a lead organisation/agency playing a coordinating and supervisory role Introduce performance standards in procurement which account for climate change risks Allocate climate change risks between public and private actors in a more transparent way e.g. in concession agreement contracts Integration and clarification of roles and responsibilities of different jurisdictions (local, national, international) Consider introducing performance standards in procurement which account for climate change risks Understand individuals' tolerance to risks resulting from the failure of infrastructure, and their willingness to pay to reduce those risks. Tariffs review could be made accordingly. Design information campaigns that use social norms for behaviour change e.g. by informing individuals about desirable behaviour of others, possibly by emphasizing the real statistical probability of different risks Information campaigns and public's expectation management of infrastructure performance under climatic stress

Decisions	Market failures	Policy Failures	Governance failures	Social and Behavioural barriers	*Examples of Solutions*
New hydro or large dams	Uncertainty and missing information on climate variability and impacts on river flows Higher uncertainty for assets with long-term life, about 100 years Natural monopoly generating externalities (irrigation, flood management, recreation) Market distortions (e.g. tariffs kept inefficiently low) Misaligned incentives of various stakeholders (benefits of adaptation reaped by different stakeholders at different times)	Lack of institutional framework and/or investment strategy that allow for climate change to be incorporated into investment decisions Lack of integration or confusion between policies, priorities and trade-offs (e.g. agriculture, irrigation and energy policies) Poor standards (e.g. design) ad safeguards (e.g. environmental) and/or lack of enforcement Poorly defined responsibilities, or lack of coordination between the various agents responsible for designing, operating and managing hydro Incentives to adapt not built into PPP contracts Cross-boundary regulations (e.g. for export projects)	Complex network of stakeholders and vested parties involved in the decision making process (planners and regulators, designers, owners, financiers and local communities) all playing a role in supporting/constraining adaptation Lengthy decision making process preventing timely response	Cognitive biases of decision makers responsible for deciding on infrastructure investment (e.g. use of complex climatic info, lack of clarity around costs and benefits of options) Lack of clarity around benefits from adaptation leading to inertia and procrastination Low access to technology Low access to finance Low access to information Lack of human, time and financial resources of institutions Customary land management activities (e.g. some crops cultivated in the reservoir area may increase sedimentation issues)	Improve understanding of climate change impact on river basins, and plants' runoff elasticity to climatic stress Develop guidelines for developers on what climatic info should be used for EIA, minimum environmental flows etc. Review regulations and design standards to incorporate climate change Allocate climate change risks between public and private actors in a more transparent way (e.g. in concession agreements) Improve monitoring of climate-triggered events (floods) Info campaigns for local communities on what to do in case of extreme events (e.g. floods) Consider introducing performance standards in procurement which account for climate change risks

Decisions	Market failures	Policy Failures	Governance failures	Social and Behavioural barriers	*Examples of Solutions*
New critical nodes, e.g. bridges	Information failure Public goods Externalities Misaligned incentives (depending on how concession contracts are built) High transaction costs (communication and sharing info)	Confusion between policies/priorities, existence of trade offs (e.g. continuity vs affordability of services) Incentives to adapt not built into PPP contracts Government agencies lack clear regulatory mandate on adaptation Poorly defined responsibilities, or lack of coordination between the various operators (particularly relevant due to interconnectivity between the infrastructure assets) Cross-boundary regulations might apply (across different jurisdictions)	Wide range of actors (private and public) involved in the decision making throughout the life of a project (financing, construction, maintenance and operation) Multiple vested parties in different jurisdictions make coordination and collaboration more complex	Cognitive biases of decision makers responsible for deciding on infrastructure investment (e.g. use of complex climatic info, lack of clarity around costs and benefits of options) Users' low capacity to adapt during emergencies/extreme events	Review regulations and design standards to incorporate climate change Consider introducing performance standards in procurement which account for climate change risks Allocate climate change risks between public and private actors in a more transparent way (e.g. in concession agreements) Integration and clarification of roles and responsibilities of different jurisdictions (local, national, international) Information sharing and collaboration across jurisdictions Improve preparedness for emergencies and disasters Continuous monitoring Improve understanding of public's willingness to pay for infrastructure resilience Information campaigns and public's expectation management of infrastructure performance under climatic stress
Forestry management	Public good Externalities Missing markets (e.g. for ecosystem services) Market distortions (distorted prices hampering the sustainable use of natural resources)	Co- existence of multiple frameworks for land use and agriculture, coastal zone management and water management, all regulating the natural environment Confusion between roles and responsibilities of different ministries (e.g. of environment, water, forestry)	Usually complex network of parties involved in the decision making of policies on forestry Difficult/expensive monitoring Illegal activities (e.g. illegal logging)	Cognitive biases of decision makers faced with great uncertainty around climate impacts and adaptive capacity of the natural environment Human systems' behavioural patterns exert additional pressure on the natural environment (e.g. no sustainable use of resources, illegal logging) Social norms and customary practices	Improve info on interdependency between manmade adaptation and the natural environment Improve info and comms on climate change impacts on ecosystems' services Clarify roles and responsibilities of different govt departments Consider community driven adaptation options Consider PES schemes

The *decisions* in the table involve multiple actors who can contribute or hamper adaptation at different times in the decision-making processes. Planners and regulators, the private sector, and the public all play a role in making the urban environment, services and infrastructure more or less resilient to climate change. Barriers to adaptation limit the ability of each actor to incorporate climate change risks into their decisions, and therefore to undertake the appropriate level of adaptation. For each decision-maker, barriers usually include a combination of economic, institutional, social and governance-related factors, and thus require a combination of instruments to address them.

Urban and spatial planning is a technical and political process concerned with the use of land and design of the urban environment, services, and transportation and distribution networks. By determining the spatial location and number of developments, and by affecting the demand for infrastructure services, decisions on urban planning are able to influence the vulnerability or resilience of the built environment and its inhabitants. A wide range of barriers exists that prevent urban planners and inhabitants to adapt to climate change: these include complex dependencies, assignment of responsibilities and the externalities involved, behavioral barriers and inertia, and the poor alignment of different regulatory frameworks that are relevant to urban planning. Incentives to adapt to climate change can be incorporated into building regulations and codes in order to reduce the exposure of the urban environment and its citizens to climate stresses and extreme events (e.g. floods, heat-waves).

Similar barriers prevent adaptation in other sectorial planning such as coastal management, water resources management and agricultural planning, which are greatly affected by the current uncertainty around the impact of climate change on the natural environment (e.g. future availability and quality of water), the integrated nature of sectors and the multiple regulatory frameworks applying to the management of natural resources (e.g. irrigation, energy generation and domestic consumption), the lack of markets (e.g. for ecosystem services), and even cultural norms and practices (e.g. customary land tenure systems and water management approaches). In all cases, barriers can be addressed through supply-type solutions (e.g. change in regulation, codes, better integrated regulatory frameworks, and clarity on roles and responsibility of different agencies) as well as demand-type (e.g. through a more sustainable use of resources and services).

Large infrastructure includes assets with long-term life span, who are expected to perform under current and future climatic scenarios (new built infrastructure, dams, critical nodes). In this case, incentives to adaptation can be incorporated into contractual agreements, such as public-private partnership (PPP) agreements. These agreements determine the roles and responsibilities of different actors in designing, building, operating and maintaining the assets, and contain provisions on risk sharing between the government and the private sector. PPP agreements lie on the fundamental principle that the private sector should assume those risks that it is best suited to manage. There are a wide range of PPP contracts, including for example build–own–operate–transfer (BOOT), a project financing arrangement wherein a private entity receives a concession from the public sector to finance, design, construct, and operate a facility stated in the concession contract; or design–build–finance–operate (DBFO), which is very similar to BOOT except that there is no actual ownership transfer. The owner of the project ultimately bears the risk of mala-adaptation, which in the case of BOOT is the private sector for the duration of the concession agreement, and the Government after that.

Regulatory bodies can set technical standards to influence the resilience of newly- constructed infrastructure. However, private companies may lack the necessary incentives to retrofit existing structures as the benefits may occur after their contacts have come to term.

Given the high interconnectivity of various critical infrastructure assets, adaptation should be undertaken to promote systems resilience, rather than sector resilience, and address system failure risks. Importantly, some damage may not be avoided (or too costly to be avoided), thus it is advised that infrastructure operators get a better understanding of users' willing to pay for service at a given level. Collaboration, planning and sharing of information between sectors would also be required to ensure systems resilience.

In the case of critical infrastructure, analysing interdependencies may be challenging as it requires a deep understanding on each component of the system, and of the links between systems on a wider scale and across jurisdictions. Given the large number of decision makers involved, governance barriers can be significant.

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