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Future Climate for Africa - Scoping Paper

The use of climate services for decision making in the ports sector

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1. Purpose of this paper

The paper has been prepared to support the scoping phase of the Future Climate for Africa[1] (FCFA) programme. The focus of the FCFA is to advance scientific knowledge, understanding and prediction of African climate variability and change on five to 40 year timescales, together with support for better integration of science into longer-term decision making, leading to improved climate risk management and the protection of lives and livelihoods.

Infrastructure is a priority area for the integration of climate science into decision making. Infrastructure which is being planned now may be operational in a future climate significantly different to the historical climate commonly used for planning and design. Existing and planned infrastructure assets may also not be able to cope sufficiently with current levels of climate variability, with climate change exacerbating future risks. This is especially true of long-lived infrastructure, operational over decades and for periods often exceeding its original design life.

This paper focuses on port infrastructure in sub-Saharan Africa. It investigates the climate change risks and the current use of climate science for decision making. It provides recommendations on the opportunities for integrating climate services within infrastructure planning and is structured as follows:

- **Section 2 – Introducing African ports**. A contextual introduction to the role of ports in development, the scale of investment in ports across Africa and the typical management arrangements for ports.
- **Section 3 – Climate risks to port infrastructure**. An overview of the risks posed by climate hazards and long term climate change on port infrastructure, and on the specific decision making issues associated with climate change and long-lived port infrastructure.
- **Section 4 - The role of climate services in long-lived infrastructure**. This provides a discussion of potential climate services in the context of long-lived port infrastructure.
- **Section 5 – Current status of climate change in port planning and decision making**. An overview of the general awareness of climate change issues, integration in policy, planning and infrastructure design.
- **Section 6 – Recommendations**. This gives recommended actions to enhance the climate resilience through awareness, research and improved policy and planning processes.

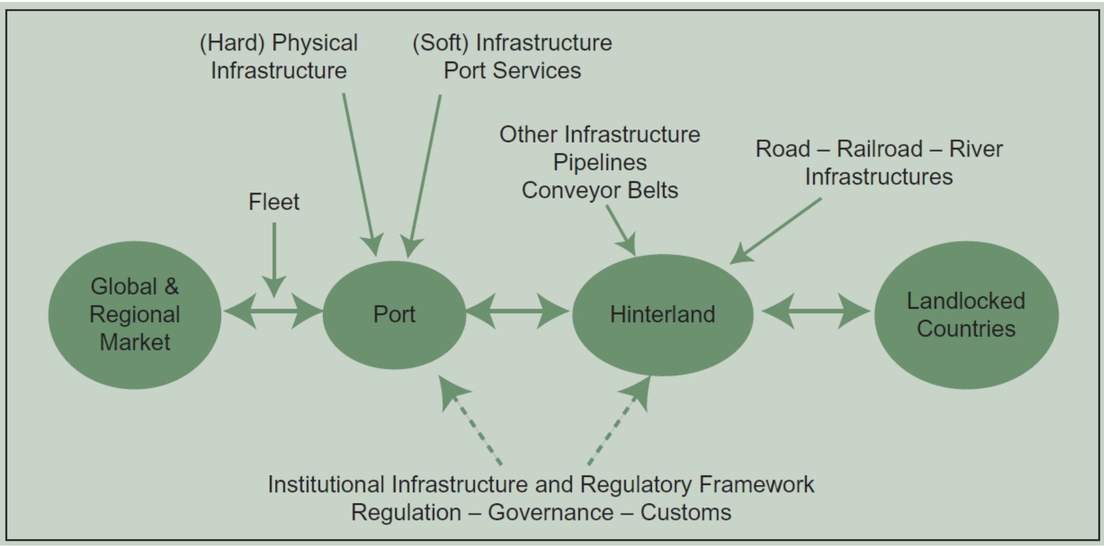
This work has been carried out through a review of existing literature and informal engagement with relevant experts.

[1] Future Climate for Africa (FCFA), is a new five-year international research programme jointly funded by the UK's Department for International Development (DFID) and the Natural Environment Research Council (NERC). The Programme will support research to better understand climate variability and change across sub-Saharan Africa. More information is available at http://www.nerc.ac.uk/research/funded/programmes/fcfa/

2. Introducing African ports

With approximately 80% of the world's merchandise trade carried by ships, maritime transport remains by far the most common mode of international freight transport. It is the backbone to facilitating international trade, offering the most economical and reliable way to move goods over long distances (AfDB, 2010). In the African context maritime transport represents the link between the African continent and global markets, as shown in Figure 2.1. For example, the Port of Durban serves the economy of not only South Africa but also provides a vital link for landlocked countries in Southern Africa including Botswana, Lesotho, Swaziland, Malawi, Zimbabwe, and Zambia (AfDB, 2010).

Relative to global trade patterns Africa is generally an exporter of raw bulk cargo, oil and gas and an importer of general and containerised processed goods (Mundy & Penfold, 2009). A range of ports exist to meet specialised needs. In terms of cargo type, ports may specialise in general cargo handling, container handling, specific import or export of dry or liquid bulk goods such as agricultural products, ores, coal, oil and gas. Ports also specialise in terms of their logistical role; hub ports serve as transhipment points for large, long distance cargo transport for distribution to smaller feeder ports serving regional markets. Some ports specialise in intercontinental transhipment of containers, but this type of port is relatively limited in Africa (AfDB, 2010). Further background on the types of ports and examples from across the continent are provided in Appendix A.



(Source: AfDB)

Figure 2.1: Diagram of ports within a global trade network

This study provides only a very brief introduction to the port sector in Africa. Further general information on the port sector, including recent trends, institutional arrangements and growth prospects can be found at the two key references in Box 2.1.

Box 2.1 – Further information on African Ports

The Africa Infrastructure Country Diagnostic

The African Development Bank flagship Africa Infrastructure Country Diagnostic contains a chapter on ports, and a background paper supporting the chapter. It collates a wide range of data, providing a valuable first port of call for gaining an overview of the sector (See Mundy & Penfold, 2009).

African Development Report 2010

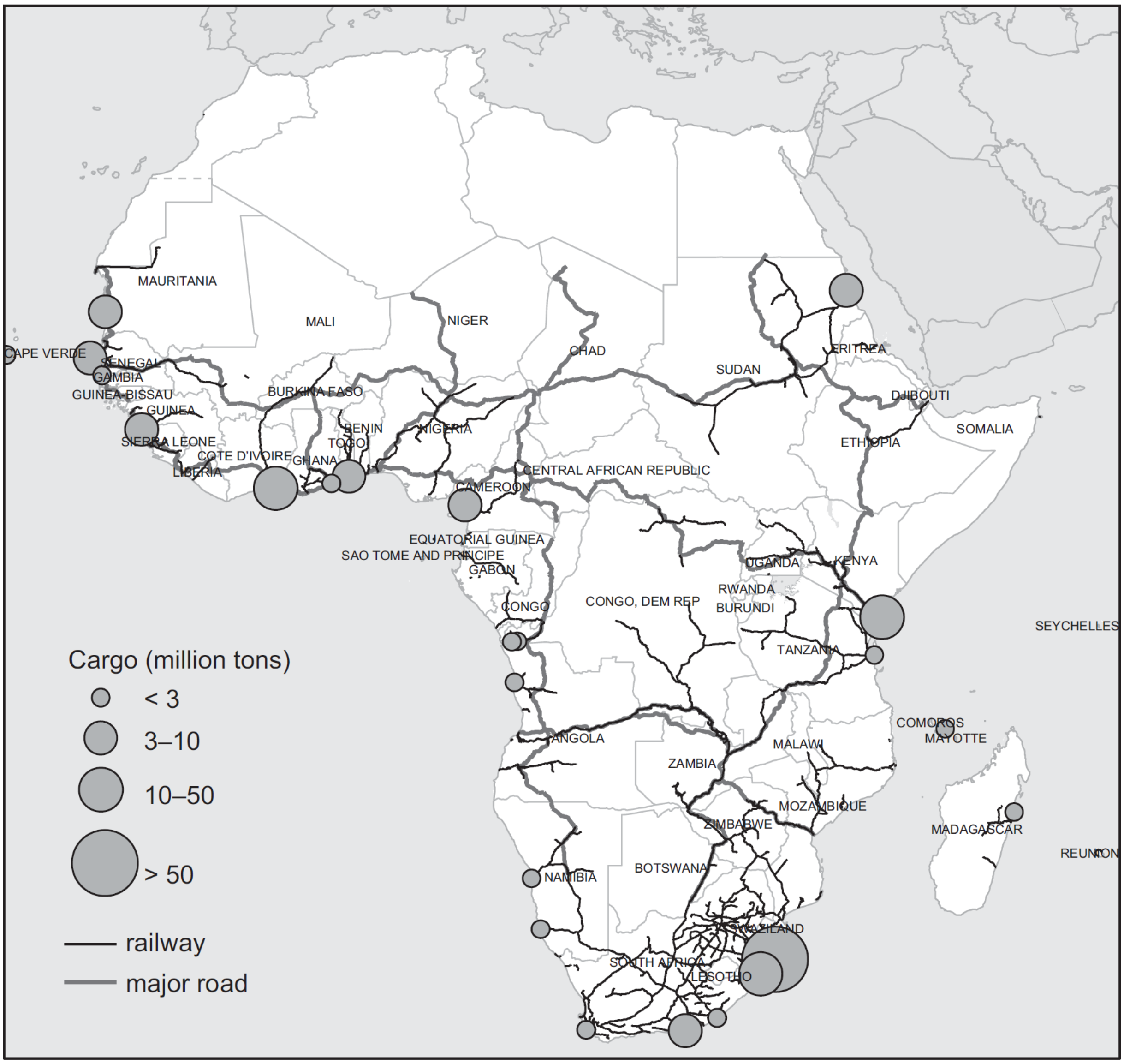
The African Development Report is an annual publication prepared by the Research Department of the African Development Bank and has become an important source of analysis and information on developments in Africa. The 2010 report was focussed thematically on the port sector, providing a comprehensive overview (See AfDB, 2010).

2.1. Investment trends and needs in port infrastructure

Since the mid-1990s, both general cargo and containerised cargo passing through African public ports have trebled (Foster & Briceno-Garmendia, 2010). This growth has put strain on port capacity, for example, the ports of Dar es Salaam, Douala, Luanda, Mombasa and Port Sudan all appear to be facing capacity constraints for general cargo traffic. At the same time, the ports of Cotonou, Dar es Salaam, Durban, Luanda, Mombasa, and Tema all appear to be facing capacity constraints for container traffic (Mundy & Penfold, 2009). Figure 2.2 shows the location of the major sub-Saharan African ports and supporting road and rail infrastructure.

Although many of the capacity problems at African ports are operational, this trend points to the need for increased investment in port development over the coming decades. At a global level the Organisation for Economic Co-operation and Development (OECD) projects a quadrupling of container traffic by 2030 (OECD, 2011) implying a substantial investment requirement for port infrastructure over the coming decades. Mundy & Penfold (2009) found new national port plans that emphasize the development of physical infrastructure, as well as institutional and regulatory reform were being undertaken in 50% of the 31 African countries in their study.

This infrastructure development will include new deep-water ports, expansion of existing ports, and the rehabilitation of port infrastructure. It will be both long-lived and subject to a range of climate risks such as storm surges, extreme waves and sea level rise. African ports are amongst those projected to see the greatest increases in exposure to coastal flooding over the coming century. Hanson and Nicholls (2012) project that Luanda, Mogadishu, Conakry and Dar-es-Salaam will experience approximately a 10 fold growth in population exposed to coastal flooding from 2005 to 2070 and while Mogadishu, Conakry, Luanda, Douala and Lagos are all in the top ten port cities globally for increases in asset exposure to coastal flood risk over the same period. These projections highlight the pace of African urbanisation and development, and the urgent need for management of climate risks in these port cities over the coming decades.



Source: (Reproduced in its entirety from Foster& Briceno-Garmendia, 2010)

Figure 2.2: Sub-Saharan Africa ports by size

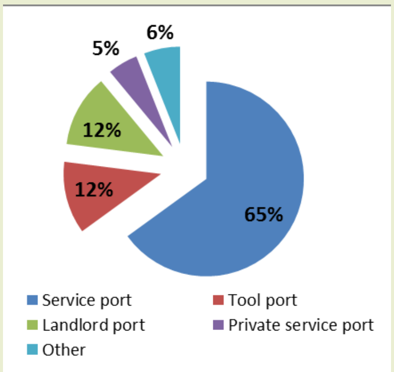
2.2. Port management models; implications for long-lived infrastructure

Ownership and operation of port infrastructure ranges from entirely public to private with a range of public-private models in between. The type of management models in use at a port will influence the stakeholders involved in decision making and the landscape of policies, regulations and other incentives which shape decision making.

At one end of the spectrum a service port is entirely publically owned and operated; the state enterprise owns the port infrastructure and undertakes all port operations. A similar situation exists in the tool port model with the exception that labour is outsourced to the private sector. The landlord model is promoted as effective and involves the public sector outsourcing many of the operational activities to the private sector. The public port body may retain ownership of basic port infrastructure, but lease berths and cargo handling space to private operators who are then responsible for managing operations and some superstructure assets. In the private service port, the entire port is owned and operated by the private sector. Table 2.1: summarises the main elements of these management models and their prevalence within Africa.

The operation of ports often benefits from private sector involvement in terms of efficiency. Private participation in port operations is generally viewed as highly successful (ADB, 2001). Africa lags behind other regions in private participation. In 2007, the top 20 global terminal operators handled only 16%of throughput in Africa, compared with about 70% in other regions of the world (Mundy & Penfold, 2009). The dominant port management model in Africa is still the public service port, although this model is beginning to change. Some statutory incorporated port agencies are being re-established as limited liability commercial companies. Ghana and Nigeria have moved toward the landlord port, where the state owns and operates major port infrastructure but allows the private sector to provide operational services (Mundy & Penfold, 2009).

Table 2.1: Summary of public and private functions for common port management structures

Port type	Infrastructure	Super-structure	Stevedoring[2] labour	Other services	Port management models in Africa (Mundy & Penfold, 2009)
Public service port	Public	Public	Public	Mainly public	
Tool port	Public	Public	Private	Mainly public	
Landlord port	Public	Private	Private	Mainly private	
Private service port	Private	Private	Private	Mainly private	

(Source: Juhel, 2010)

Based on the prevalence of the service port, and move towards landlord models, major long-lived infrastructure at ports such as piers, breakwaters, jetties and channels, for example will continue to be developed and managed by the government. The significant capital investment in basic port infrastructure and its often nationally strategic importance for development means government investment in port development is usually required (World Bank, 2007). Box 2.2 explains in more detail the disincentives to private sector investment in major port infrastructure, and the incentive to keep it public.

[2] Labour involved in cargo handling operations

Box 2.2 – Public and private incentives for long-lived port infrastructure development in Africa (

Port operations require several categories of long-lived assets, some of which are more amenable to private investments than others. Charges for infrastructure equipment (on-dock storage and transshipment facilities) can be awarded through competition, whereas charges for breakwaters, channels and turning basins are essentially a public good with a high marginal benefit and a low marginal cost, so that a private operator would make a monopoly profit by charging a price based on user benefits. Should this last category of high-cost infrastructure be placed in the hands of private operators (as it would under the private sector model, as indicated in Table 2.1), the private sector investors would face a high-risk tradeoff between their ability to set prices independently without regulatory constraint when considering their very long-term investment decision. This explains why countries with weak governance may fail to procure the hoped-for investment from the private sector in a reform that concessions services of long-lived assets to the private sector.

The increasing importance of adequate regulation with private sector involvement may help explain the patterns of public–private involvement in the port subsector across Africa, which is dominated by the publically operated service port model. Investing in high-cost and long-term infrastructure carries high risks for the private sector, in the absence of an independent and autonomous regulatory framework (such an institutional framework is considered as “best-practice” for the port subsector). Consequently, in Africa one observes few instances of landlord and private services ports where the superstructure and equipment are privately owned.

(Source: AfDB, 2010)

3. Climate risks to port infrastructure

Ports are highly vulnerable to climate related impacts (Becker et al. 2013). Their location in often dynamic coastal environments places them at risk from storm surges, extreme waves, high winds and extreme rainfall. Box 3.1 provides an example of climate hazards facing the port of Walvis Bay, Namibia. Ports’ standard asset management procedures involve managing climate risks such as the impacts of wave damage on structures, the effects of sedimentation and scour and drainage amongst other risk factors (Central Dredging Association, 2012). Climate change will alter the levels of risk, consequently altering the maintenance requirements on existing ports and the levels of risk which should be considered during planning of new ports. Sea level rise also brings slow onset change, which will incrementally increase the impacts of existing hazards on ports over the coming century (Becker et al. 2013).

Climate hazards result in immediate impacts on port infrastructure and operations such as damage to assets, operational delays and health and safety risks to staff. These in turn have secondary economic, social and environmental consequences. Operational delays due to severe weather, or closure of facilities can have serious financial implications for ports and all the stakeholders which depend on their operation. The social consequences of port delays and closures will be felt by those employed directly or indirectly through the trade and commerce system reliant on port services.

Climate change will alter the frequency and severity of climate related impacts. Hallegatte (2007) (in Becker et al. 2012) found a 10% increase in storm intensity would increase annual hurricane damage in the USA by 54%, from US$8 billion to US$2 billion per year. Another recent study found that land surrounding ports at 35 of 44 Caribbean ports would be inundated by a 1 m rise in sea level, unless protected by new coastal structures (Simpson et al. 2010, in Becker et al. 2012).

Box 3.1 – Potential impacts of climate change on Walvis Bay, Namibia (based on Rossouw & Theron, 2012)

Walvis Bay is Namibia's main harbour and only deep water port, providing a national economic hub for Namibia and access to seaborne freight services for landlocked countries such as Botswana.

During seasonal storms waves wash over the major sand spit protecting the bay. A breach in the sand spit would be disastrous for the port, exposing it directly to storm waves (see Figure 3.1). A breach occurred at a similar anchorage at Baia dos Tigres in Angola, forming an island and destroying the potential for safe anchorage.

Rising sea level and changing storm characteristics may increase the risk of such a breach occurring the future, although projections on changing storm conditions are highly uncertain (Church et al., 2013), hence it is difficult in practice to estimate the level of risk associated with the breach occurring at present on in the future.

The largely AfDB financed planned expansion of Walvis bay has incorporated the consideration of climate change into the planning and design process, including relevant Environmental and Social Assessment Procedures (AfDB, 2013). There may be a role for AfDB due diligence processes as an entry point for incorporate climate risks in port planning more generally.

Figure 3.1: Map of Walvis Bay showing sand spit protecting the port (*Google Maps, 2014)*

Table 3.1 below summarises direct climate impacts on ports including how climate change may influence the changes in these impacts over time. Appendix B provides further information on relevant climate change projections for Africa.

Table 3.1:Summary of climate hazards to port assets

Climate hazard	Impact of climate hazard on ports	Influence of climate change on impact	Summary of Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) projections for Africa (IPCC, 2013)
Extreme waves / storm surge	• Damage to major structures (for example, quay walls, jetties, breakwaters) • Damage to port super-structure (e.g. cranes, buildings, land based transport) • Damage to floating assets, vessels and cargo • Operational delays in berthing and handling • Disruption to ancillary services (e.g. power, water) and off port transport networks • Risk to life • Release of pollutants	Sea level rise could increase the potential for flooding during storm surge events Changing storm intensity could increase extreme wave conditions	**Sea level rise** between 17cm and 38cm by 2050s and 26cm to 82cm by 2090s (includes emission scenario uncertainty), Africa broadly consistent with global projections (see Appendix B.1) Increased incidence and/or magnitude of **extreme high sea level** is likely in the early part of the 21st century and very likely by the later part of the 21st century. This increase will primarily be the result of an increase in mean sea level (high confidence), with extreme return periods decreasing by at least an order of magnitude in some regions by the end of the 21st century. There is low confidence in region-specific projections of storminess and associated storm surges. (see Appendix B.1) General trend towards decreasing frequency of **tropical cyclones** but increasing intensity. However, confidence is low in regional projections (see Appendix B.2)
Long term wave and current climate controlling sediment and coastal morphology	• Damage to assets and limited navigation resulting from sedimentation and scour around port structure and channels.	Changing waves and current patterns could increase sedimentation and scour	Regional estimates are not feasible. Quantitative estimates require detailed local hydrodynamic modelling studies to provide estimates of how changes in sea levels and wind climates impact on sediment and coastal morphology.
Extremes of rainfall resulting in river floods and low flows	• Damage to assets and limited navigation resulting from high sediment loads and scour around port structure and channels. • Low flows limiting navigation in inland ports	Changing extreme rainfall conditions could increase sediment loads from river systems	Increased **average runoff** projected across East Africa, reductions in average runoff across Southern Africa. Confidence in projections are variable across Africa (see Appendix B.5). General trend towards increasing **intensity of storm rainfall** across the continent, although the trend is more pronounced in East Africa than North Africa for example (see Appendix B.4)
Extreme rainfall resulting in surface water flooding of ports	• Damage to port super-structure (e.g. cranes, buildings, land based transport) • Damage to cargo • Operational delays in berthing and handling • Risk to life • Release of pollutants	Changes in rainfall intensity could increase the risk of surface water flooding	General trend towards increasing **intensity of storm rainfall** across the continent, although the trend is more pronounced in East Africa than North Africa for example (see Appendix B.4)
High winds	• Damage to port super-structure (cranes, buildings, land based transport) • Damage to vessels and floating assets • Operational delays in berthing and handling • Risk to life	Changes in storm wind intensity could increase risk	It is likely (medium confidence) that **annual mean significant wave heights** will increase in the Southern Ocean as a result of enhanced wind speeds. Southern Ocean generated swells are likely to affect heights, periods and directions of waves in adjacent basins. In general, there is low confidence in region-specific projections due to the low confidence in tropical and extra-tropical storm projections, and to the challenge of down-scaling future wind states from coarse resolution climate models (see Appendix B.3)

Source: synthesised from NCCOE (2004) and Stenek et al. (2011)) and generalised climate change projections extracted from IPCC (2013) and CDKN (2012)

3.1. The implications of climate change for long-lived port infrastructure decision making

Long-lived infrastructure is inherently exposed to climate risks through its longevity, irreversibility and high initial capital cost (Ranger, 2013). Major transport infrastructure is often designed for a lifetime measured in many decades. Figure 3.2 presents global climate change projections for temperature for two emissions scenarios, showing the range of possible futures, with uncertainties increasing further into the future. Indicative infrastructure lifetimes (based on construction in the year 2000) are plotted on to the projections showing the range of climate futures which the infrastructure may be subjected to over its lifetime. Many bridges, ports, road and railway lines remain in their original design location for centuries even if the infrastructure on them has been rehabilitated or replaced several times (IPCC, 2014a).

Long-lived infrastructure is generally designed to accommodate an estimated level of climate variability based on historical records. This may be highly uncertain in itself, depending on the length and quality of available data on variability. When future climate change over the design life of the infrastructure is considered, this uncertainty is substantially increased as the historical record becomes less valid for future planning, and a reliance is placed on the use of uncertain climate model outputs.

The implications of climate patterns which are different from those anticipated during infrastructure planning can mean increased maintenance costs, service interruptions, and reduced safety of port operations, as set out in Table 3.1.

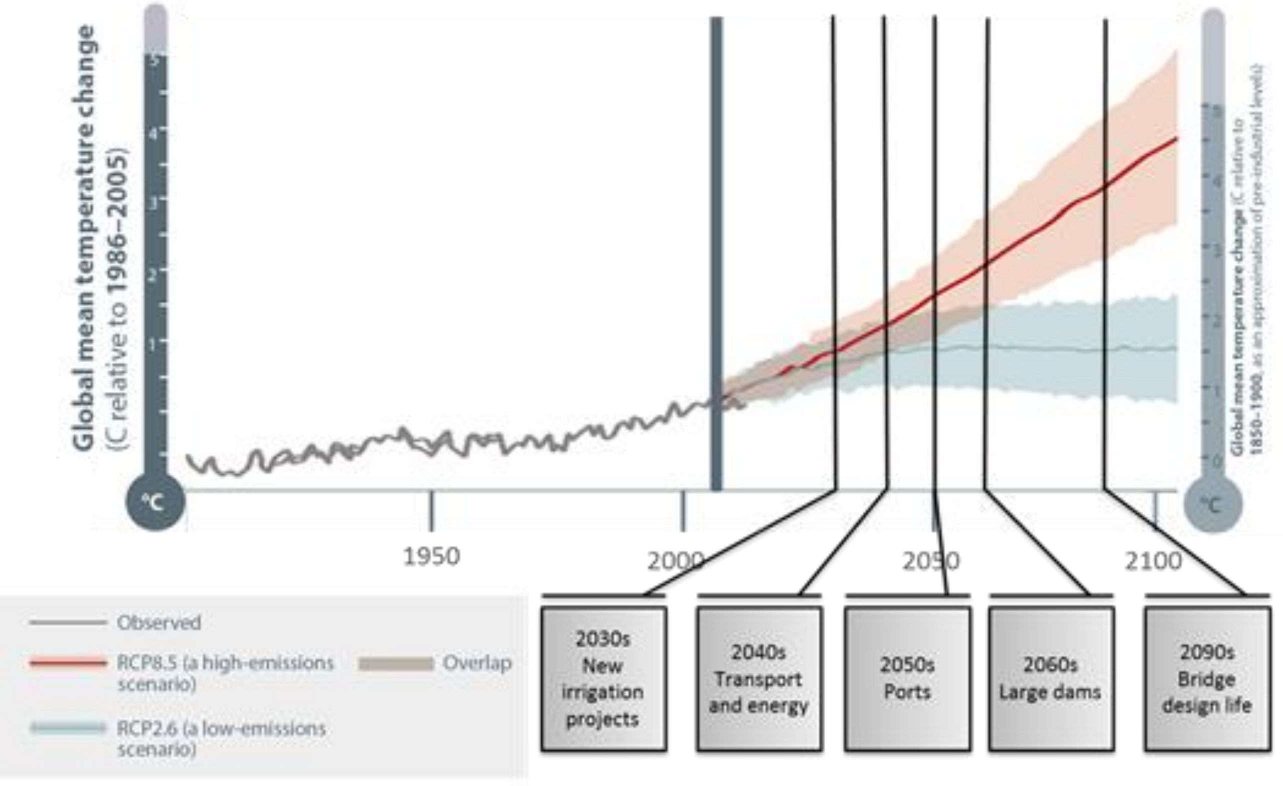


Figure 3.2: Indicative timescales of a range of planning activities compared with timescales for climate change (Note that infrastructure lifetimes are indicative and will vary considerably in practice)

Source: *(Source: Adapted from IPCC (2014) with selected infrastructure lifetimes from Stafford Smith et al. (2011) and UNCTAD (1985))*

One strategy to address these uncertainties is to allow in the design for future conditions that would be more severe than those occurring at present. For example, an allowance for sea level rise is commonly applied when designing coastal structures, and this can also lead to the need to allow for higher wave heights. (Peter Hunter, pers comm 2014). However, this results in additional costs which may or may not prove to be cost-beneficial depending on how climate change manifests itself. If the design criteria or safety factors can be increased for relatively little additional cost then the level of ‘regret’ is low, such actions are often termed ‘low-regret’.

An alternative strategy is to try to maintain flexibility in infrastructure planning over time to reduce the investment ‘locked in’ to any one particular set of assumptions on future climate, for example by building into a structure a provision for future upgrading to meet more severe conditions if and when they occur. This often requires complex scenario analysis of a range of development options under a range of different future climates to develop a pathway of actions which can be adjusted in the future (see Ranger (2013) for a more comprehensive discussion of decision making under uncertainty). Maintaining flexibility may cost more than selecting a single fixed solution, but as it can be adjusted in the future as conditions change, it will be ‘robust’ across a range of potential future climates. In practice the potential for flexibility in port infrastructure appears to be limited, although much more research is required into the costs and benefits of adopting more flexible approaches to port infrastructure (Zwakhals et al. 2012). One example of a flexible approach is the embankment of the Cardiff Bay Barrage in the UK, which was designed to accommodate a defined sea level rise; however,, its design allows the crest level to be raised in the future if sea level rise is greater than anticipated (Peter Hunter, pers. comm. 2014).

Maintaining flexibility has co-benefits relative to other non-climate uncertainties, such as changing socio-economic demands on the infrastructure over time. In the context of port infrastructure non-climate uncertainties are considerable. One example is in the continuing trend for larger ocean going cargo vessels which can make port infrastructure obsolete over relatively short timescales. The Delta Peninsula section of the Port of Rotterdam was developed in the 1990s, barely 10 years' later the port was forced to consider redevelopment to accept larger vessels (Zwakhals et al. 2012).

The potential for flexibility at the planning stage is relatively high, with many different potential solutions available to meet the desired objective, each of which can be evaluated against future climate. Once infrastructure is in place, flexibility is more limited. If no physical alterations are feasible it relies on managing the residual risks which cannot be offset at the design phase. This can include management or operational practices such as forecasting and warning to manage climate hazards as they arise. These types of activities are inherently adaptable and can be improved and adjusted into the future, while the assets themselves remain fixed.

Guidance on port master planning developed by PIANC (the World Association for Waterborne Transport Infrastructure) promotes flexibility as a guiding philosophy for master planning over the 20 to 30 year time horizons typical of port master plans (PIANC, 2014). Flexibility is promoted to manage the risks associated with uncertainty in future traffic, legislation, technology and hinterland transport development amongst others. A phased approach to port development is recommended to maintain flexibility, around a set of broad port zoning principles and an overall port layout.

Although climate change is not cited as a specific reason to maintain flexibility, the overall philosophy may help support resilience to climate risks by allowing ports to adapt their development to meet changing future conditions, in terms of both climate and non-climate risk factors. The use of discount rates used in the financial analysis of port development projects also plays a role in maintaining flexibility. High discount rates have the effect of favouring smaller projects with a relatively short construction phase. Big projects with a relatively long construction phase and, therefore, delayed benefits may therefore be disadvantaged compared to smaller and phased alternatives (PIANC, 2014).

4. The role of climate services for long-lived infrastructure planning

Climate services can play a role in supporting the resilience of long-lived infrastructure to climate variability and change. This requires a clear understanding of what constitutes climate services in this context. The World Meteorological Organization (WMO) Global Framework on Climate Services provides a definition of climate services which is provided below.

> Climate services encompass a range of activities that deal with generating and providing information based on past, present and future climate and on its impacts on natural and human systems. Climate services include the use of simple information like historical climate data sets as well as more complex products such as predictions of weather elements on monthly, seasonal or decadal timescales, also making use of climate projections according to different greenhouse gas emission scenarios. Included as well are information and support that help the user choose the right product for the decision they need to make and that explain the uncertainty associated with the information offered while advising on how to best use it in the decision-making process
>
> *(WMO, 2011).*

This definition views climate services as providing the data, information and evidence to inform decision making processes. It also acknowledges the need to advise on how best to apply climate information in the decision making process.

However, the demand for climate services from port authorities and other stakeholders is essential for the sustainable uptake and use of climate services into mainstream decision making processes. This demand can be driven by top-down regulatory requirements, bottom up awareness from port authorities themselves and a range of other factors such as insurance and investor demands.

This section discusses the types of climate services relevant to long-lived port infrastructure while the issue of the enabling environment supporting demand and uptake of climate services is discussed in section 5.

4.1. Climate services relevant to long-lived port infrastructure

The climate services supporting decision making can broadly be classified as static or real time services. The former might include climate change projections, hazard maps or estimates of extreme rainfall conditions which can be used at the planning process for site selection and infrastructure design, through tools such as design guidance. The latter might include real time forecasting or warning to manage climate hazards such as storm events which may be forecasted days ahead, or to plan asset maintenance on a seasonal basis for example. Table 4.1 gives an indicative framing of the types of climate services which are relevant to port planning and the decision making activities which they support.

Climate services in Table 4.1 comprise both services which are beneficial in the absence of climate change, such as hazard forecasting as well as those which specifically address the non-stationary nature of future climate, such as climate change projections.

The use of hazard forecasting enhances resilience to climate risks in the short term, regardless of future uncertainty over climate change. It may also increase the adaptive capacity of the port through a greater awareness and understanding of the impacts of climate hazards on operations and infrastructure. This type of activity can be considered 'low regret' in managing the residual risks which cannot reasonably be offset through infrastructure design.

In contrast, planning for long-lived infrastructure requires the consideration of climate risks decades into the future to determine the most robust means of accommodating future uncertainties, both in terms of climate change and development of the transport sector in general. This paper mainly focusses on the consideration of long term climate change in long-lived infrastructure, but acknowledges that low regrets activities for managing current levels of risk will also support resilience.

Table 4.1:Types of climate services and the decision making processes potentially supported

	Short term (< 10 days) weather forecasting	**Medium term (10 days to 1 year) seasonal weather forecasting**	**Long term (>10 years) climate change projections, and baseline climate**
Climate services	Short term forecasts of key variables such as wave heights, wind speed, storm surge	Medium term forecasts of storminess, extreme tide levels	Historical climate data Assessments of the impacts of observed hazards Projections of change in key variables such as wave heights, wind speed, storm surge
Decision making processes	Managing risks to operational activities such as berthing and cargo handling	Planning and scheduling operational activities, e.g. maintenance	Strategic port planning Feasibility and design of infrastructure

The use of climate services for planning requires an enabling environment to support the uptake and mainstreaming of climate services into standard practices. This environment can take a variety of forms including:

- General awareness of climate change issues within the industry;
- Policy and regulatory framework which supports the consideration of long term climate change; and
- Decision making tools and guidelines which incorporate climate change.

Section 5 examines the current status of these within decision making practices.

5. Current status of climate change in port planning and decision making

Climate change adds a new dimension to the management of climate risks. The stationarity which has been assumed for planning and operational purposes is no longer valid and decision making processes must adapt to ensure ports can maintain their services in a changing climate.

The scientific literature on the potential impacts of climate change on ports is relatively plentiful, albeit more limited in the African context. However, information on what ports are doing about climate risks and climate change in general is less readily available in the literature.

This section reviews the use of climate services for long-lived port infrastructure, being specific to Africa where possible, but drawing inferences from global reviews where this is not possible. The following themes have been used to organise the review:

- Awareness and perception of climate change issues;
- Policy and regulatory frameworks for port planning;
- Integrating climate change in port design.

5.1. Awareness and perception of climate change issues

A prerequisite to the uptake and use of climate services for decision making is a broad level of awareness and perception of the need for action amongst decision makers.

Becker et al. (2012) undertook one of the few surveys of the knowledge and practice of port administrators relating to climate change. The survey received 93 responses from ports worldwide with respondents including port directors, engineers, environmental managers and planners. It provides a useful snapshot of industry practice on climate change, with the caveat that survey respondents may be skewed towards ports which are already taking an interest in climate change issues. Only five responses were received from African ports, with 43 from North America, 17 from Europe, 17 from Asia, seven from the Americas and four from Oceania. The distribution of ports is heavily skewed towards North America. However, the dominance of Asia, North America and Europe in terms of maritime trade (UNCTAD, 2013) means that proportionately fewer large ports exist in Africa than the three dominant world regions, and a small number of responses from African ports would be expected.

Although the authors found little evidence of difference in climate change policy across these regions, ports in lower income countries were found to lag high income countries slightly in terms of climate change policy. However, the small sample size from Africa reduces the confidence in this conclusion for Africa in particular.

47% of ports in the Becker et al. (2012) survey either did not know, or were not addressing climate change adaptation issues. The remainder showed varying levels of climate change related policies and activities including meetings on adaptation, climate change included in design guidance, climate change insurance, climate change in strategic planning and other plans and budgeting.

Becker et al. (2012) found the primary climate change related impacts of concern to port administrators are sea level rise and the impacts associated with changing storm characteristics. 86% of respondents felt climate change should be addressed by the port community, while 66% felt uninformed on the issue. This highlights an awareness of climate change issues which has not been translated into detailed understanding of the risks or practical actions to manage risks.

Participants were also asked who they felt knew the most about climate change adaptation, with responses divided between environmental planning, the chief engineer and the port director. This fragmentation indicates the breadth of areas which climate change links into, and the difficulty in housing such a cross cutting issue with any one department.

This finding concurs with that of a study conducted on the US Gulf Coast (Leonard et al. 2008) with State Departments of Transportation (DOT) and Metropolitan Planning Organizations (MPO). The authors found no evidence of climate change being formally considered in planning documents, although the majority had been developed prior to Hurricane Katrina and the recent increased interest in climate change issues in the USA in general. Participants in the study felt climate change was an important concern but were limited in their freedom to undertake change in decision making approaches without a drive from higher levels of government. The study recommended the introduction of risk assessment, the use of probabilistic information on climate change and new tools for decision making to supplement the traditionally deterministic planning approaches.

Finally, planning horizons are identified as a constraint on the ability of planners to incorporate climate change projections. In the Becker et al (2012) survey 75% of ports reported planning horizons to be less than 10 years. Given the large uncertainties associated with projecting the demand for port services into the future, this is not surprising. However, this needs to be reconciled with the fact that some physical infrastructure such as quays and breakwaters may have life spans well beyond their initial planning horizon.

5.1.1. Industry initiatives for climate change adaptation

Beyond the awareness and perception of climate change at the individual port level, port associations at the national, regional and international level also acts as barometers of the current state of best practice across the industry in terms of climate change risk management.

At the international level both PIANC (the World Association for Waterborne Transport Infrastructure) and International Association of Ports and Harbours (IAPH) have programmes of work related to climate change (see Box 5.1), with the IAPH being involved in the Becker et al. (2012) study referenced above. Much work has been focussed on mitigation activities, but adaptation is increasingly being recognised as an issue (Inoue, 2012).

At the regional scale three regional associations exist, covering East and South Africa, West Africa and North Africa respectively. They are:

- The Port Management Association of Eastern and Southern Africa (PMAESA);
- The Port Management Association of West and Central Africa (PMAWCA);
- The North Africa Port Management Association (NAPMA).

A pan-African association, the Pan Africa Association for Port Cooperation (PAPC) draws together these regional associations with the broad objectives of fostering dialogue, engaging with the international community, promoting African interests, increasing the efficiency and productivity of African ports, capacity development and information sharing.

Given the above objectives, these associations could potentially provide valuable entry points to stimulate awareness and dialogue on climate change issues at national and port level. The extent to which these organisations are aware of climate change issues and whether this is reflected in their work programmes is unclear and requires further research.

Box 5.1 – Port industry initiatives engaging with climate change adaptation

PIANC (the World Association for Waterborne Transport Infrastructure)

PIANC has established a Permanent Task Group on Climate Change (PTG CC). The PTG CC comprises national experts, representatives of the PIANC Commissions and Sister Association representatives and is undertaking a variety of activities with respect to climate change and navigation, including a review of whether PIANC Working Group reports appropriately take into account climate change issues. Their present website[3] gives the results of the PTG CC's work.

International Association of Ports and Harbours (IAPH)

In 2008, the IAPH requested its Port Environment Committee, in consultation with regional Port Organizations, to provide a mechanism for assisting the ports to combat climate change. This resulted in the World Ports Climate Initiative (WPCI) with a mission to:

- Raise awareness in the port and maritime community of need for action
- Initiate studies, strategies and actions to reduce greenhouse gas emissions and improve air quality
- Provide a platform for the maritime port sector for the exchange of information thereon
- Make available information on the effects of climate change on the maritime port environment and measures for its mitigation

Although the primary aim of the WPCI relates to climate change mitigation, adaptation is also rising on the agenda with the IAPH (Inoue, 2012). At present the membership of the WPCI is entirely made up of North American and European ports.

Key conclusions:

- **The industry is aware of climate change as an issue but translation into practical action in port planning is more limited.**
- **Responsibility for climate change issues can lie with a number of different stakeholders involved in port management including environmental planning, the chief engineer and the port director.**
- **Short port planning horizons (relative to climate change) are a barrier to the consideration of climate change in planning.**
- **Understanding the differences in awareness of climate change issues between Africa and the rest of the world is hampered by lack of Africa specific data in the available literature.**
- **African port associations could provide valuable entry points raise to awareness on climate change issues, although the extent of current awareness amongst these organisation is not known.**

5.2. Policy and regulatory frameworks for port planning

The policy and regulatory environment within which ports are developed and operated vary considerably depending on port development model which is utilised. As discussed in section 2.3, this can vary from entirely public to entirely private. The long-lived infrastructure components of ports in Africa are almost entirely publically planned and owned, whereas the operation of ports and is moving from public to some private sector participation (AfDB, 2010).

[3] http://www.pianc.org/climatechange.php

The two crucial agencies involved in African port development and regulation are the Ministry of Transport and the Port Authority. The regulatory agencies responsible in a number of African countries are summarised in Table 5.1.

Table 5.1: Port management models and regulatory agencies in selected African countries

Country	Management Model	Agency responsible for regulation
Angola	Part landlord, part service port	Ministry of Transport, Merchant Marine and Ports Division
Benin	Service port	Port Autonome de Cotonou
Cameroon	Part landlord, part service port	National Ports Authority
Cape Verde	Service port	NA
Congo (Brazzaville)	Service port	Port Autonome de Pointe Noire
Côte d'Ivoire	Part landlord, part service port	The Autonomous Port of Abidjan
Democratic Republic of the Congo	Service port	NA
Djibouti	Management concession	Ministry of Transport
Ghana	Landlord model	Ghana Ports and Harbor Authority
Kenya	Service port	Ministry of Information, Transport, and Communications
Madagascar	Part landlord, part service port	NA
Namibia	Service port	Namibian Ports Authority
Nigeria	Landlord model	Nigerian Ports Authority
Senegal	Part landlord, part service port	Direction of Ports and the Interior Maritime Transport
South Africa	Service port	Transnet National Ports Authority
Sudan	Service port	Sudan Sea Ports Corp
Tanzania	Part landlord, part service port	Tanzania Ports Authority

(Source: AfDB, 2010)

Typically, the Ministry of Transport oversees the development of transport and port policies and the preparation and implementation of transport and port laws, national regulations, and decrees (AfDB, 2010). The Ministry also prepares financial and economic analyses to evaluate the socio-economic and financial feasibility of projects, taking the context of national policies and priorities into account (AfDB, 2010).

At the level of implementing regulation, the Ministry of Transport, Port Authority (national or local) is usually responsible for the following executive functions related to infrastructure development (AfDB, 2010):

- The execution of the national port policy;
- The construction of protective works, sea locks, port entrances, the control of port state;
- The regulatory and licensing functions; and the construction and maintenance of the vessel traffic systems and aids to navigation and the search and rescue functions.

Since, in Africa, ports are owned and most operated by public bodies the regulatory duties are not independent of operational activities. Ideally, an independent regulator should be given autonomy to undertake these functions although in Africa there is no evidence of independent regulation of ports outside South Africa (AfDB, 2010). Indeed, the Port of Durban in South Africa provides an interesting example of the use of the Environmental Impact Assessment (EIA) process to mainstream the consideration of climate change in port planning (see Box 5.2).

Box 5.2 – The use of Environmental Impact Assessment (EIA) to mainstream the consideration of climate change, Port of Durban, South Africa

The Port of Durban, South Africa is Africa's second busiest container port (by throughput) and is crucial to supporting the economies of landlocked states in southern Africa (AfDB, 2010). Its advanced container handling facilities have made it an important regional hub, although congestion on connecting road routes is problematic. Substantial investments are planned which include increasing the capacity of berths to accept larger vessels.

However, the Environmental Impact Assessment (EIA) for part of the development was rejected by the Department of Environmental Affairs on the grounds that climate change risks were not sufficiently addressed in the EIA (Business Day Live, 2014). This resulted in the resubmission of the EIA and changes to the planned designs to incorporate climate change risks (see Box 5.3).

It provides an example of the regulatory tools which can be used (in this case the EIA process) to mainstream the consideration of climate change risks.

This institutional arrangement means that in terms of decision making on long-lived infrastructure development, the Ministry of Transport and the Port Authority are the two key stakeholders at the centre of strategic port planning, including development of infrastructure. This study has been able to find no readily accessible information on the nature and extent of the policies and regulation which the Ministry of Transport and Port Authority are subject to. It is not possible to comment on how effective these instruments are in promoting the consideration of climate change in strategic planning processes. This represents a significant opportunity for further research.

Port master plans typically guide the development of physical infrastructure over several decades and can thus be a useful entry point for understanding the extent to which climate risks, and long term climate change, are considered. New master plans for the port sector were either recently introduced or are under development in Namibia, South Africa, Tanzania and ten countries in West Africa (Gwilliam, 2011). Again, to our knowledge no review of these master plans has been undertaken and this would be a valuable contribution to assessing their consideration of climate change.

Key conclusions:

- **Ports are typically publically owned and operated in Africa, Ministries of Transport and Port Authorities lead the development of infrastructure and are not independently regulated.**
- **Port master plans are a key entry point for influencing the inclusion of climate change in long term planning but little evidence is available on the extent to which climate change is considered.**

5.3. Integrating climate change in port design

Design guidance is a key tool for steering the specifications for infrastructure design (although, not necessarily long term investment planning). International and national public and industry bodies produce best practice guidance on the design of port infrastructure. Climate change can be either included in existing design guidance manuals, or thematic supplementary guidance on climate change can be produced to be used alongside existing guidance.

These design criteria represent the storm severity (i.e. wind speed, water level, wave height, currents) which infrastructure should be able to withstand. Most ports use a 1 in 100 year return period (1% annual probability) storm design standard for infrastructure, although some use the most extreme observed storm on record. Changes in storm intensity and severity, coupled with sea level rise could mean that present day design standards offer a lower level of protection in the future (Becker et al. 2012). It is unclear whether the design guidance containing these standards acknowledges climate change or provides guidance on increasing the design standards to offset future changes in risks. Such a decision requires a consideration of the costs and benefits of investment in higher levels of service to offset an uncertain future risk. In some cases applying a safety factor to accommodate uncertainty may add an acceptably small additional cost to the design, in which case the safety factor is 'low regret'. However, in the case of significant additional cost, it may be more difficult to justify the potentially wasted over investment in safety. Little research has been carried out to provide evidence on the additional costs and benefits of applying additional allowance for to incorporating climate change uncertainty. Such research would support the development of guidance on these types of allowances.

The globalised and public / private mix of port ownership, investment and operation makes the use of design guidance rather fragmented between countries and port operators. In developing country contexts design guidance from other countries (e.g.UK, Australia, USA and Spain) are commonly used where national standards do not exist. Selection of particular standards often reflects the experience and preferences of the project proponents, consultants and contractors (Peter Hunter, pers comm. 2014).

In many cases design guidance includes provisions for sea level rise, but rarely contains changes in wind speed or wave height or storm surges (Peter Hunter, pers comm. 2014). The general impression across the industry is that the uncertainty in changes in these variables limits the practicality of their inclusion in design guidance (Peter Hunter, pers comm. 2014). It implies the need for more readily accessible and understandable projections of the key variables which are of interest to port designers and engineers, and continued work to reduce scientific uncertainty. Such resources would help the industry to determine whether these variables should be integrated within design guidance.

Box 5.3 gives the example of a structural design at the Port of Durban which makes use of climate change projections for sea level rise as well as other climate variables including storm surge, wind speed and extreme rainfall.

Key conclusions:

- **Design guidance often incorporates sea level rise projections, but projections in changes in other variables such as storminess, rainfall and temperature are rarely considered.**
- **A number of different design manuals are used across Africa depending on the port developer involved and consulting engineers used.**
- **Uncertainty in climate change projections is a barrier to their incorporation in deterministic design approaches which typically involves the use of additional safety factors to accommodate uncertainty.**

Box 5.3: Including climate change in engineering design for deepening berths Port of Durban

This case study gives an example of how, in practice, engineers have incorporated climate change into structural designs for berths in the Port of Durban. It is an interesting example of the interpretation of climate change projections into pragmatic alterations to structural designs enhancing their resilience to climate change. The requirement to make these adjustments has arisen from the rejection of an Environmental Impact Assessment by the Department of Environmental Affairs (see Box 5.2).

Essentially the approach uses additional safety factors based around climate impacts on structural elements of the design. This will result in an additional cost to the project, which has not been assessed. Another option would have been to not include climate change safety factors and adjust the design at a later date. This feasibility of maintaining such flexibility was also not assessed. However, the approach illustrates that climate change can be pragmatically accommodated in standard design processes, without the need for substantial additional planning work or the need for specialist support in advanced decision making techniques.

The design of the structures was adjusted to accommodate climate change as follows:

Sea level rise - Freeboard on the design was increased to accommodate sea level rise over the 50 year life span of the project, using a conservative assumption of 580mm sea level rise representing the 95th percentile upper bound of the IPCC Fifth Assessment report central estimate for sea level rise.

Wind speed - A 5% increase in wind loading has been factored into the design on the basis of International Atomic Energy Agency (IAEA) guidance which stipulates an allowance of 5 to 10% increase for a 100 year design life. Note that this factor has been developed for nuclear facilities, which are highly vulnerable to climate hazards and therefore demand high safety factors. Therefore it may be overly conservative for port infrastructure.

Storm surge - A simple model using wind speed was used to apply the 5% wind speed factor. This resulted in an estimated increase of storm surge height of 10% which has been included in the freeboard.

Extreme rainfall - Although considered less critical to the design. A 10% increase in extreme rainfall was incorporated in the design of the site drainage system to offset the risk of increased storm rainfall in the future. This value was based on the Durban Climate Change Strategy - Water Theme Report: Draft for Public Comment, January 2014"

Figure 5.1: Containers in the Port of Durban (Wikimedia Commons)

(Source: ZAA, 2014)

6. Recommendations

Recommendations for enhancing the climate resilience of long-lived port infrastructure include a broad range of actions from awareness and perception to adjustment of decision making processes and tools. Given the relative scarcity of information on the processes and tools used by African ports for decision making, further research and engagement with the industry is a central recommendation. This will be core to building an evidence base to steer any further practical actions. Building on existing stakeholder networks and on the body of existing research will be important to maximise value of future research.

At the broadest level, Becker et al. 2012 notes "On a global scale, most ports are in the beginning stages of considering adaptation to climate change. There is an opportunity for the scientific community to engage with this sector to create the knowledge base needed to understand and improve the resilience and efficiency in the coming century"

Recommendations are based around the thematic headings in section 5:

- Awareness and perception of climate change issues;
- Policy and regulatory frameworks and climate change;
- Decision making tools for port planning which support climate resilience.

6.1. Recommendations on awareness and perception of climate change

A close dialogue between the climate science community and industry is required to align demand and supply of climate services. The port industry is generally aware of climate change as an issue but translation of this awareness into practical application is limited. There is a need for a close working relationship between industry practitioners and climate change specialists to develop appropriate information products and tools to integrate these into existing decision making practices. This is an iterative process of dialogue which will build greater understanding and demand for services, while focussing the climate science community on the needs of decision makers in industry.

Potential activities include:

- Building on existing industry forums such as the World Meteorological Organisation (WMO) climate services platform and relevant industry bodies (see Box 5.1), open a dialogue between industry stakeholders and climate scientists. This should focus on applied climate science and those roles in industry which most closely relate to the management of climate risks. It should also build on existing research programmes where these exist.
- Sharing of knowledge and best practice in climate change adaptation planning between ports, facilitated by the industry and the international development community. Becker et al (2012) note that "this is an opportunity for ports in higher-income countries to share some of their climate planning tools and knowledge with those who have not yet taken steps towards adaptation".

Awareness raising and knowledge sharing on what constitutes good practice in terms of adapting to climate change is required to demonstrate how adaptation is implemented. Much theoretical work has been completed on the potential impacts of climate change on ports. A major challenge arises in turning this theory into practical application at the port level.

Activities could include:

- Collating existing research and commissioning new research into the economics of adapting ports to climate change. This could include aspects such as the costs and benefits of over-designing infrastructure for an uncertain future climate, and the economics of maintaining flexibility in infrastructure, for adaptation at a future date.

- Developing case studies of decision making tools which successfully and pragmatically incorporate climate change risks and uncertainties into planning processes and using these as a basis for knowledge sharing on good practice across the industry.

6.2. Recommendations on policy and regulatory frameworks for port development

Undertaking further research on the institutional environment for decision making will be important to understand how decisions around long-lived infrastructure are made and the extent of incentives and policies to support the management of climate change risks. There is little information on the policies, legislation, regulation and other guidance which supports decision making processes and the extent to which they support climate resilience. Studies are generally limited to Europe and North America. A comprehensive policy mapping for the African ports sector, assessing the extent to which the policy environment supports climate resilience would be a useful contribution to the knowledge base.

This type of research could pose the following research questions:

- What is the extent of national climate change policies and how to these address transport, maritime transport and port development?
- What is the extent of climate change policy at sectoral level and on a port by port basis? Reviewing transport and infrastructure planning policies will reveal the extent to which Ministries of Transport and Port Authorities are considering climate risks.
- Which stakeholders are involved in port development planning, especially for infrastructure and what policies and guidelines are being used to support the process?
- How is climate change and climate risk management addressed in port development plans?
- What are the regulatory tools used to guide port development planning and what opportunities exist for mainstreaming the consideration of climate risks in these tools? This could include EIA, spatial planning laws, project economic and technical appraisal guidelines amongst others.
- What impact do project financiers such as the African Development Bank (AfDB) have on the inclusion of climate change in planning and design, and how does this compare with domestic and privately raised finance?

Such research could be undertaken through detailed stakeholder engagement at a small number of ports, supplemented by a broader institutional review across a broader range of ports. This work would build on existing studies such as Becker et al. (2012) and provide Africa specific conclusions.

Climate change policies can provide an entry point for reviewing port planning processes, and infrastructure development processes in general. A review of the status of ports in climate change policy can identify good practice and opportunities to add value to existing policies. Box 6.1 gives the example of the use of climate change legislation in the UK to drive change at a sectoral level.

Box 6.1: Use of legislation as a tool to mandate climate change risk assessment

In the United Kingdom, the Climate Change Act 2008 requires harbour authorities handling over 10 million tonnes cargo per year to report on the risks climate change poses to their activities to the government Department for Environment, Food and Rural Affairs.

This is an example of the use of national legislation as a tool to implement climate change adaptation. In requiring ports to report on these issues awareness of climate change impacts are raised within the port community, and an evidence base is compiled for public sector policymakers on the risks posed to nationally significant infrastructure and freight systems.

As an example of the reporting undertaken, Associated British Ports (ABP) undertook a risk assessment of the ports of the Humber, Hull, Immingham and Southampton for which is the harbour authority (Associated British Ports, 2011)

The assessment considers the functions of a harbour authority and concludes that engineering, dredging, vessel traffic services, and pilotage functions could be vulnerable to climate change. It also considers these functions against key hazards due to climate change. The key climate change hazards that were considered to be likely to impact on our functions were related to sea level rise / flooding, temperature changes, and storm events. The highest priority risks were associated with the Vessel Traffic Service (VTS) and engineering roles, and the projected impacts associated with sea level rise and flooding, temperature increases and storminess.

Risks were prioritised, mitigation actions identified and the risks were mainstreamed into the port's Marine Safety Management System.

Figure 6.1: Port of Immingham (reproduced from Associated British Ports (2011)

Reviewing port master plans and planning guidelines for Africa will help to provide an understanding of how climate change is considered in planning processes. Port master plans are a key entry point to understand the decision making process for planning long-lived infrastructure at ports. Potential activities could include:

- A review of master plans to understand the extent to which climate risks and climate change are included in planning, including whether risk assessments and scenario planning are utilised will identify opportunities for enhancing the master planning process.
- Identifying examples of good practice in master planning both in Africa and globally and the development of case studies and transferrable knowledge and tools to target the improvement of African port master plans when they are due for revision.

6.3. Recommendations for design guidance

Infrastructure designers require clear and simple guidance on projected changes in variables which influence their designs. Sea level rise projections are the most well understood climate change variable and are already incorporated in some design guidance. Projections in other variables such as extreme wave height, wind speed and surge level (associated with changes in storminess) are generally not considered during design, other than where directly linked to sea level rise, due to the high uncertainty in climate change projections on these variables (Peter Hunter, pers comm. 2014) (Rossouw & Theron, 2012). Potential activities to support this recommendation could include:

- Engaging stakeholders including experts in coastal structure design, coastal scientists and climate scientists to identify those variables which designers would require guidance on climate change when planning new infrastructure.
- Development of simple projections which aim to quantify the range of changes in relevant variables which can be digested by planners and designers. This should include uncertainty ranges and guidance on incorporating climate change uncertainty in decision making.

Although not strictly related to long term climate change, the effective management of existing climate hazards as they impact on operational activities can offset changes in climate. This includes effective forecasting of hazards and implementation of operational protocols to manage risk. This paper has not assessed the extent to which ports make use of climate services for these purposes hence it is not possible to identify detailed policy recommendations. General recommendations include:

- Undertaking an international review on the use of, and benefits accrued from hazard warning for port operations. This should include an assessment of the barriers to successful implementation for hazard warning, especially in the context of African ports. It should provide recommendation on best practices and knowledge transfer within the industry as well as climate services which should be developed to support improvements in hazard warning where needs are identified.

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Appendices

A. Types of ports according to function

This section has been (reproduced from AfDB, 2010) and provides an introduction to the main types of port by function, giving examples from Africa.

- **General Cargo Ports** are medium-sized ports (including container terminals) with a large enough volume to attract frequent direct vessel calls. Volumes are typically between 2 to 10 million tonnes per annum (pa) and 100,000 to 500,000 Twenty foot Equivalent Units (TEUs) pa. Examples of general cargo ports include Port Elizabeth in South Africa and Walvis Bay in Namibia. Most general cargo ports have ambitions to expand into regional hubs.
- **Hub Ports** are large regional ports, with high volumes of direct large-vessel calls. They service a large catchment area, which also serves the smaller regional ports by transshipping containers and general cargo in smaller vessels. Typical examples are Durban in South Africa and Port Said in Egypt. These two ports are ranked among the 60 largest ports in the world in terms of container volume throughput (over 2 million TEUs p.a.).
- **Feeder Ports** are normally smaller ports with limited vessel calls and depth restrictions. They are unable to attract many direct vessel calls because of the small volumes of trade they handle (generally less than 100,000 TEUs pa). These ports are mostly fed by smaller coastal services from the regional hub ports. The Mozambican and Angolan ports and many of the West African ports are typical examples. The feeder service and the double handling of containers add to the overall logistics costs.
- **Bulk Ports** are mainly dedicated to handling large volumes of bulk materials, accommodating Cape size vessels, with depths of 18 to25 m, generally without dedicated container terminals. Typical examples are Richards Bay (coal) and Saldanha Bay (iron ore) in South Africa and Port Saco in Angola and Buchanan in Liberia, both handling iron ore.
- **Transshipment terminals** or ports are large container terminals where cargo is transferred from one carrier to another, or from one type of vessel to another. Examples of transshipment terminals include the ports of Algiers, Durban, Mombasa, and Djibouti. Transshipment terminals handle very large container vessels (above 6,000 TEUs), which very few African ports can handle. Vessels of more than 15,000 TEUs are now in service and these vessels require a quayside depth of 16 to 18 m (such as Singapore port, and Salalah in Oman). The new port of Ngqura in South Africa, with a depth of 16 m, has been developed as a transshipment port and will receive large vessels from the east and trans-ship to smaller vessels for the East and West African coasts.
- **Dedicated oil terminals** handle crude oil which is most often transported in large capesize vessels of 120,000 to 150,000 dead weight tonnage (dwt), which require greater water depths than can be provided at any of the African ports currently. Oil tankers are mostly handled at offshore moorings which are linked to landside storage tanks via submarine pipelines. This is the case for the ports of Durban in South Africa, Dar es Salaam in Tanzania, and Cabinda in Angola. Some ports, such as Cape Town in South Africa, have dedicated tanker basins.
- **River Ports** are generally small and isolated, and do not serve oceangoing vessels. One notable exception is Matadi port in the Democratic Republic of Congo (DRC), which is 150 km from the coast and serves as the country's main port, but with restricted depth. There is currently a project proposal for the development of a port on the Zambezi/Shire River waterway to serve Malawi, which will require dredging of sections of the river system. However, this development is subject to an economic feasibility study and a positive outcome of an environmental impact assessment.

B. IPCC projections of variables relevant to ports

This section presents evidence from the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment report on the projections of climate change which are of relevance to the impacts discussed above. It is intended to provide an overview of the changes and uncertainties within the current science, illustrating the issues with providing climate services based on climate change projections.

Figure B.1 provides an illustrative spread of uncertainties around port relevant climate change variables. It highlights that temperature and sea level rise, with their uni-directional projections of change are the most certain, whereas wind, waves and sediment transport are less well understood and more dependent on local conditions. For example, sea level rise projections around African coasts can be placed in an envelope of uncertainty, whereas the complex mechanisms driving tropical cyclones and their associated wind and wave impacts are much less well understood with little clarity on the directions of change, let alone a quantitative estimate.

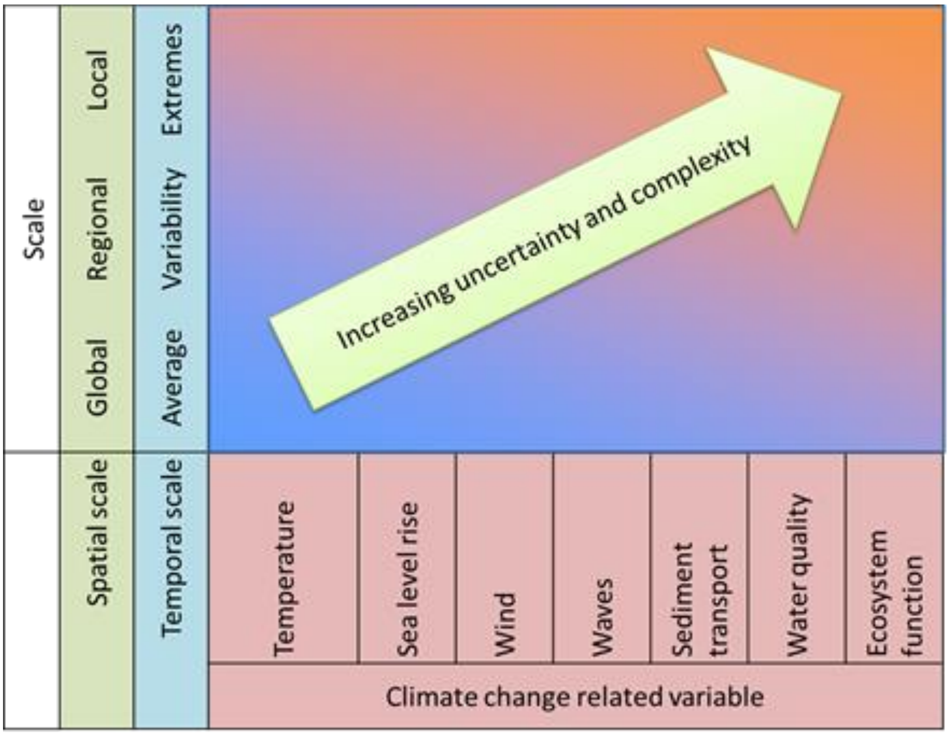

Figure B.1: Illustration of the increasing levels of uncertainty associated with climate change projections for different variables related tom ports, and the scale or granularity required of the projections.

Source: (adapted from PIANC, 2008)

B.1. Sea level rise and storm surge

It is very likely that there will be a significant increase in the occurrence of future sea level extremes by the end of the 21st century, with a likely increase in the early 21st century. This increase will primarily be the result of an increase in mean sea level (high confidence), with extreme return periods decreasing by at least an order of magnitude in some regions by the end of the 21st century. There is low confidence in region-specific projections of storminess and associated storm surges. (IPCC, 2013). Figure B.2 shows global mean sea level projections, and B.3 shows their spatial variability, Africa approximately follows the global trend.

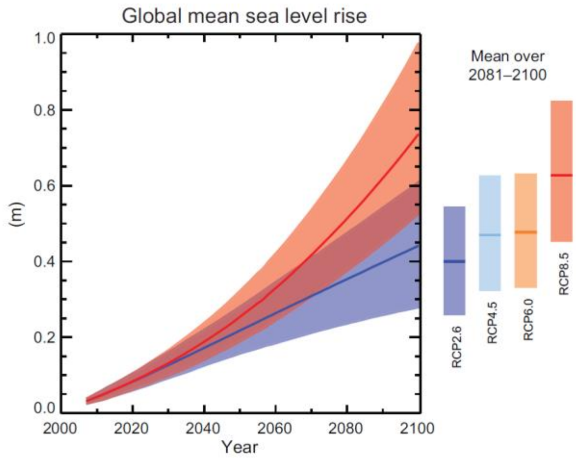

Figure B.2: Projections from process-based models of global mean sea level (GMSL) rise relative to 1986–2005 for the four RCP scenarios. The solid lines show the median projections, the dashed lines show the likely ranges for RCP4.5 and RCP6.0, and the shading the likely ranges for RCP2.6 and RCP8.5. The time means for 2081–2100 are shown as coloured vertical bars.

Source: (reproduced from Stocker et al 2013)

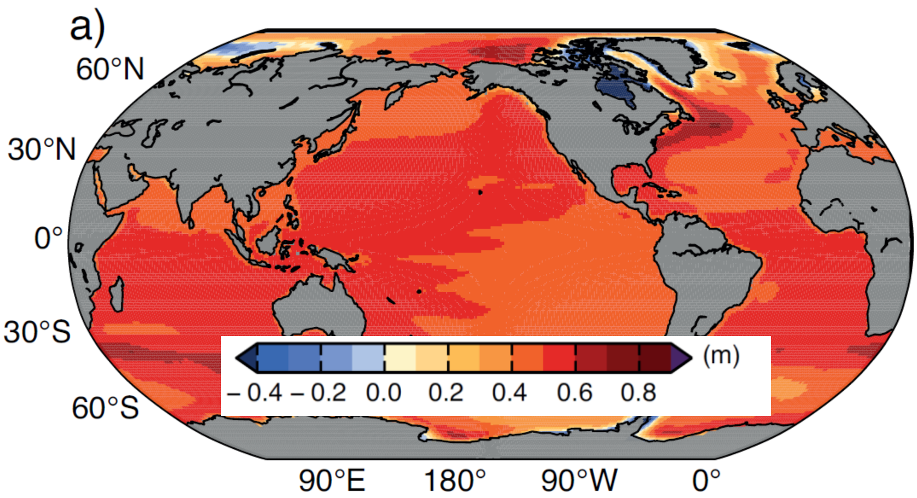

Figure B.3: Ensemble mean regional relative sea level change (m) evaluated from 21 models of the CMIP5 scenario RCP 4.5, including atmospheric loading, plus land-ice, GIA and terrestrial water sources, between 1986–2005 and 2081–2100. Global mean is 0.48 m, with a total range of -1.74 to +0.71 m

Source: Reproduced form Church et al. (2013)

B.2. Tropical cyclones

Tropical cyclones are a major threat along the Madagascar and Mozambique coast. About two cyclones per year enter the Mozambique Channel, while one per year makes landfall (Rossouw & Theron, 2012) . Cyclones bring wind and wave conditions which can be damaging and disruptive to port operations. Figure B.4 shows the location of ports within 50km of historical storm tracks, highlighting the risk posed to Mozambique and Madagascan coasts.

While projections indicate that it is likely that the global frequency of tropical cyclones will either decrease or remain essentially unchanged, concurrent with a likely increase in both global mean tropical cyclone maximum wind speed and rainfall rates, there is lower confidence in region-specific projections of frequency and intensity. However, due to improvements in model resolution and downscaling techniques, it is more likely than not that the frequency of the most intense storms will increase substantially in some basins under projected 21st century warming (IPCC, 2013).

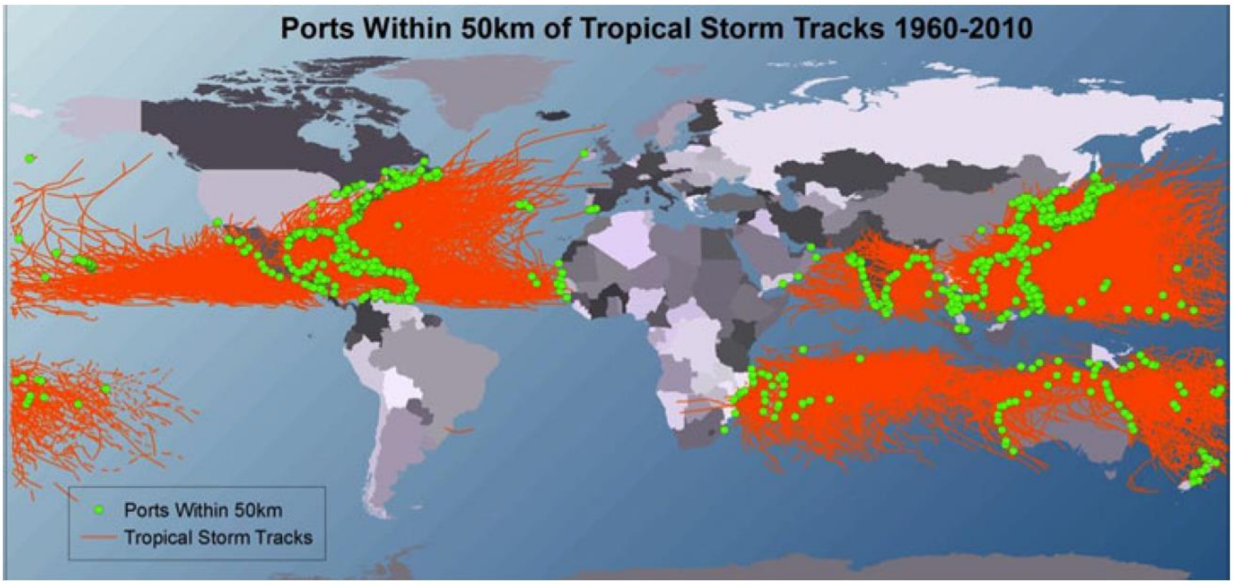

Figure B.4: Ports within 50 km of tropical storm tracks, 1960–2010. Port and storm data from National Geospatial-Intelligence Agency (2011) and Knapp et al. (2010)

Source: reproduced from Becker et al. (2013)

B.3. Extreme wind speed and wave height

Changes in extreme wave heights have implications for the exposure of infrastructure such as breakwaters, quay walls and on the operation of ship navigation and berthing. Figure B.5 shows the projected change in significant wave height illustrating a both increases and decreases globally, and the relative uncertainty of projections around African coasts.

It is likely (medium confidence) that annual mean significant wave heights will increase in the Southern Ocean as a result of enhanced wind speeds. Southern Ocean–generated swells are likely to affect heights, periods and directions of waves in adjacent basins. It is very likely that wave heights and the duration of the wave season will increase in the Arctic Ocean as a result of reduced sea ice extent. In general, there is low confidence in region-specific projections due to the low confidence in tropical and extra-tropical storm projections, and to the challenge of down-scaling future wind states from coarse resolution climate models (IPCC, 2013).

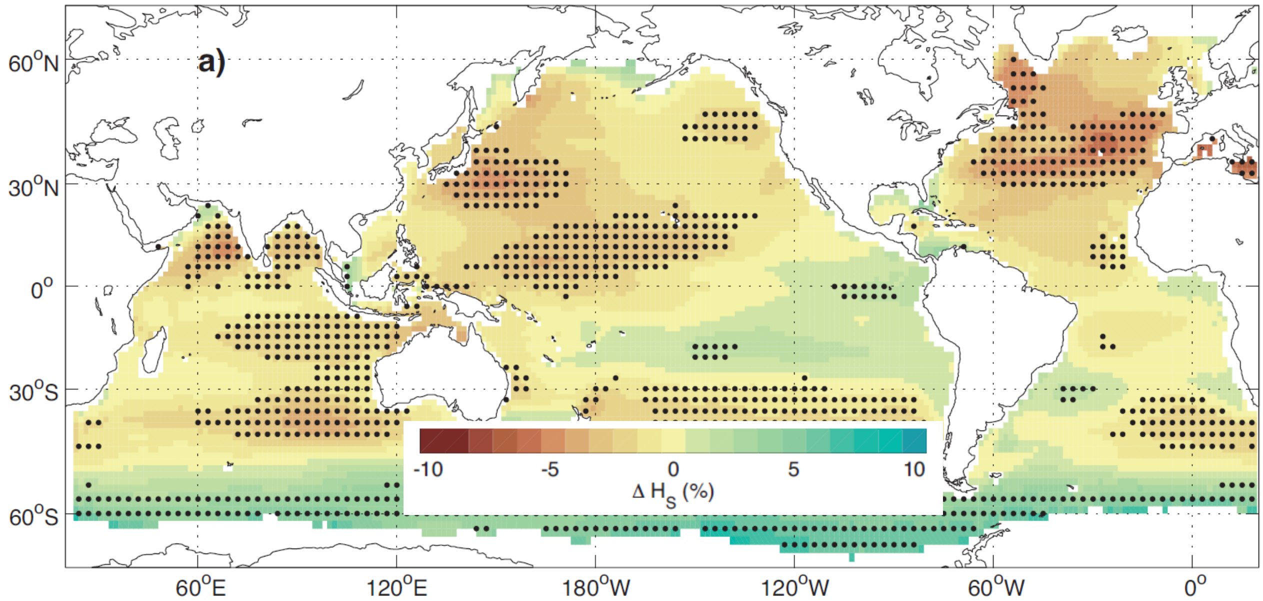

Figure B.5: Projected changes in wind–wave conditions (~2075–2100 compared with ~1980–2009) derived from the Coordinated Ocean Wave Climate Projection (COWCLIP) Project (Hemer et al., 2013). (a) Percentage difference in annual mean significant wave height. Hashed regions indicate projected change is greater than the 5-member ensemble standard deviation.

Source: reproduced from Church et al. (2013)

B.4. Extreme rainfall

Extreme rainfall can have implications for flooding of land side infrastructure and transport links associated with port operations.

Figure B.6 shows how often the wettest day in the last 20 years of the 20th century will be experienced by the middle and end of the 21st century. These are shown under three different emissions scenarios: B1, A1B and A2. For example this shows that in East Africa the wettest day will become more frequent under any scenario and time period, whereas for the Sahara, increases in extreme rainfall occurrence are projected to be less frequent.

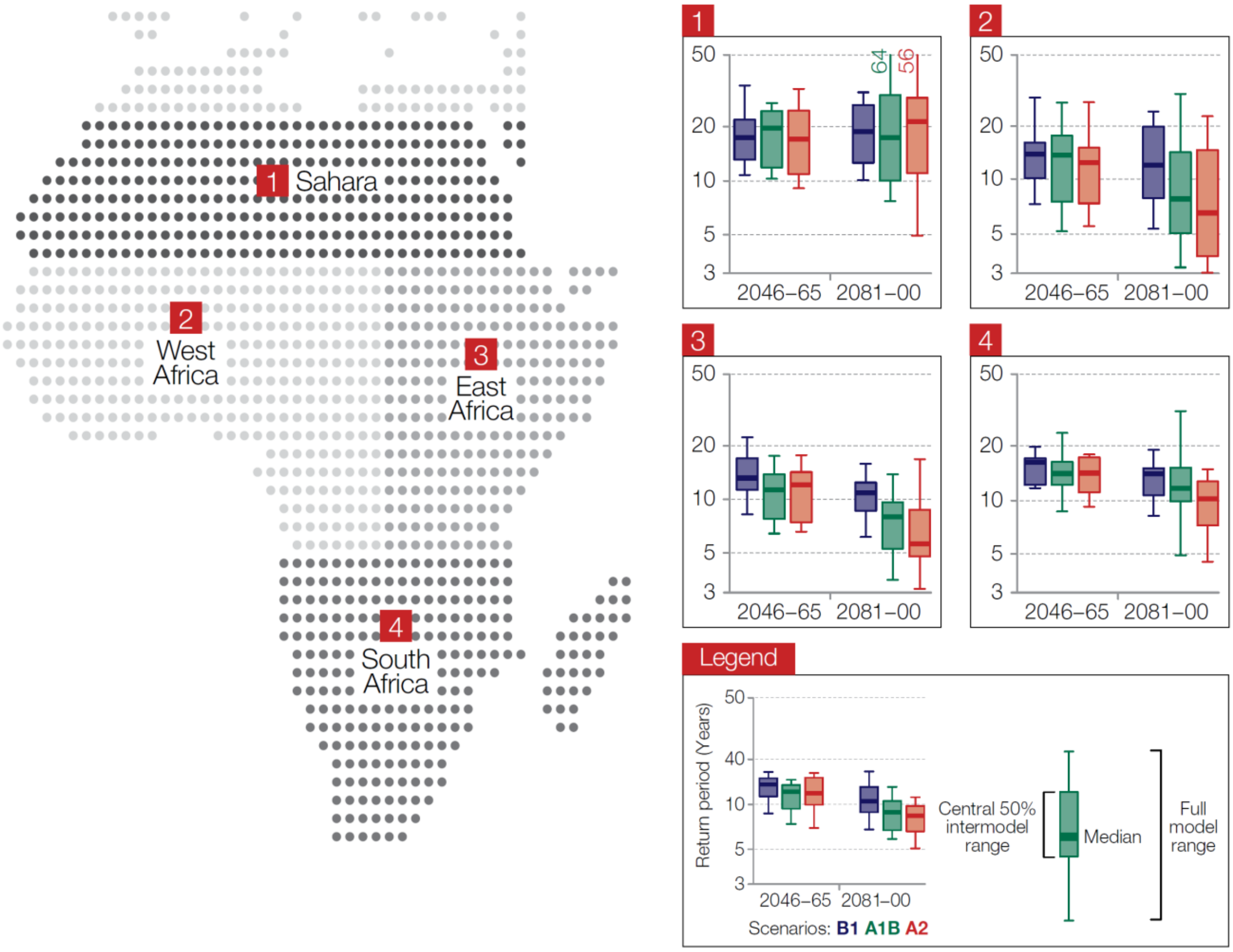

Figure B.6: Projected changes in extreme rainfall for African regions

Source: reproduced from CDKN (2012)

B.5. River runoff

Figure B.7 shows changes in the annual mean changes runoff for Africa for the period 2081 to 2100 relative to the period 1986 to 2005 based on the result of 33 Global Climate Models. It shows that runoff in East Africa is likely to increase, whilst runoff in Southern Africa is likely to decrease. It is important to note that the figure only shows mean annual changes in runoff, seasonal changes and extremes are not captured. For example, in Southern Africa, although Figure B.7 shows a general reduction in mean runoff, Figure B.6 shows a general increase in extreme rainfall intensity. This makes generalisations about river characteristics difficult; on the one hand lower river flows might limit navigation in tidal and river ports, on the other more intense extreme rainfall may increase the likelihood of periodic flooding of ports from rivers. Conversely, in East Africa, the increase in both mean runoff and extreme rainfall points towards higher average and flood flows.

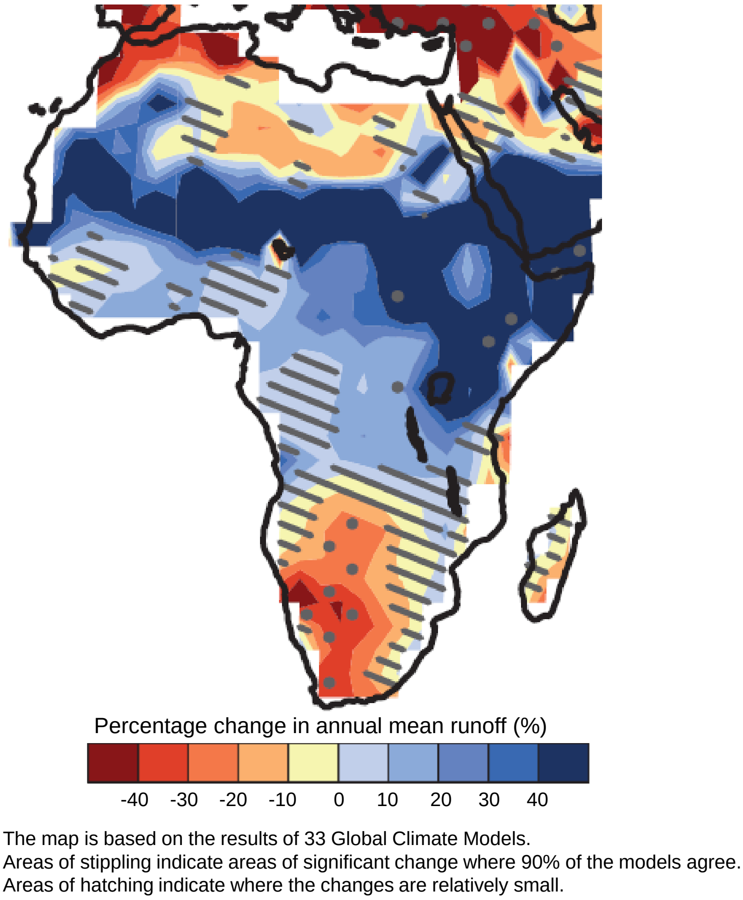

Figure B.7: Mean annual percentage increase in runoff for Africa for the period 2081 to 2100

Source: IPCC (2013)

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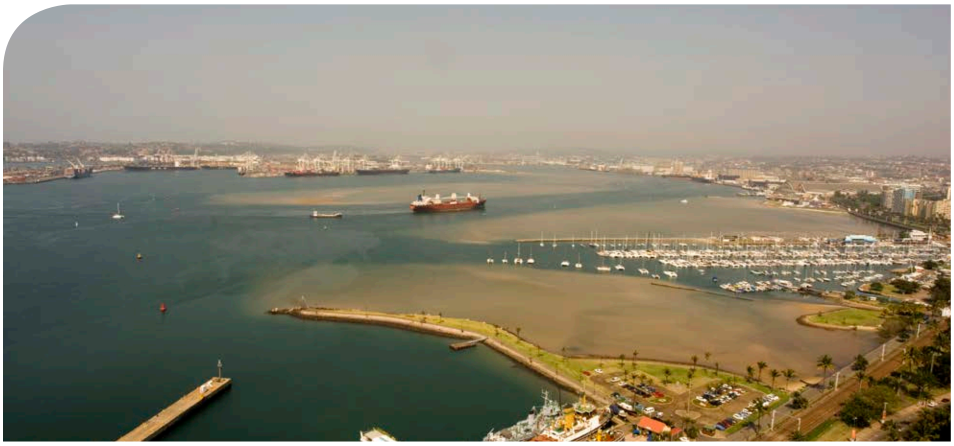
Working with water



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