Report from the lookout
–
Understanding climate change impacts on shipping

M. Traut[1], S. Hanson[2], and C. Walsh[1]

[1]Tyndall Centre for Climate Change Research, University of Manchester
[2]Tyndall Centre for Climate Change Research, University of Southampton

ABSTRACT
Many elements of sea transport may be affected by climate change. Some impacts may act on the supply of, others on the demand for shipping. Some may be more direct, others more indirect. Overall, climate change impacts are characterised by significant complexity and uncertainty. Scenarios can be a useful tool to explore uncertain futures. This paper explores causal chains linking climate change to shipping. A first case study estimates grain production, demand, and resultant import dependency in Egypt and Nigeria. A second case study analyses resultant stresses on the major ports of Alexandria (Egypt) and Lagos (Nigeria), compounded by projected sea level rise. Both case studies are framed by two wider climate change scenarios being developed in the Shipping in Changing Climates project. The two case studies are interlinked; but each draws on different methodologies (and literature) suited to the matter. The case studies illustrate the pathway towards a better understanding of the risks and opportunities which climate change may hold for the sector. Furthermore, the impact scenarios may form part of the wider suite of future scenarios for the shipping sector under the Shipping in Changing Climate project, contrasting high and low mitigation futures, across a range of socio-economic scenarios from the climate change literature.

Keywords: Climate change, impacts, adaptation, mitigation, scenarios, shipping

1. Introduction
With annual CO_2 emissions of the order of one gigatonne, the shipping sector is responsible for a significant share of global CO_2 emissions which are of the order of 40 gigatonnes per year. Consequently, much of the debate, at the International Maritime Organization and in other fora, is focussed on mitigation options, and on the question what role shipping can play in the global effort to cut CO_2 emissions in line with global temperature targets. Most of the research in the *Shipping in Changing Climates* (SCC) project follows from this question, too. This paper follows a complementary question: how will climate change affect shipping? In a sense, the latter question encompasses the former: the need for mitigation in the shipping sector is an –indirect– impact of climate change. Indirect or direct, affecting supply or demand, and short, medium, or long term with respect to onset and duration, are categories for characterising climate impacts laid out in previous work (Traut et al., 2015). Some of the biggest risks from climate change to the shipping sector may be indirect, which makes them hard to assess. In (Traut et al., 2015), indirect impacts are defined as a chain comprising many causal impact links, with a view to making them amenable to analysis – with the best-suited analysis tool applied to each respective link. The present paper brings life to this concept, by presenting two interlinked case studies: on the potential climate change impact on grain production,

demand, and resultant import dependency in Egypt and Nigeria; and on the implications, compounded by sea level rise, for Alexandria and Lagos, major ports in those countries.

The following Section 2 introduces the SCC scenarios, providing the context for the case studies. Section 3 recaps how climate change impacts may be parsed. The two case studies are presented in Sections 4 and 5. They are discussed in Section 6, while Section 7 reflects on the use of model results associated with great uncertainty before Section 8 concludes.

2. Scenarios in the Shipping Changing Climates project

A set of future scenarios are being developed in the *Shipping in Changing Climates (SCC)* project. The scenarios provide a context for the future evolution of the shipping sector. One key element of the scenarios are contrasting future manifestations of climate change, framed around a global temperature rise of 2°C and 4°C, respectively. At the lower end of this spectrum, it is possible –albeit with large ranges of uncertainty– to map increases in global temperature to cumulative emissions of CO_2. In turn, it is possible to assess how a future trajectory of CO_2 emissions from the shipping sector fits with global climate change mitigation targets, or, the other way around, to determine a cumulative shipping emissions budget as a share of a global budget in line with a given mitigation target (Traut & Anderson, 2014). With respect to physical climate change impacts, 2°C scenarios are informed by Earth system model runs of RCP2.6, while 4°C scenarios are informed by model runs of RCP8.5.

Building on the contrasting framings of climate change in terms of global temperature increase, four scenarios of sectoral economic growth, international trade, and demand for sea transport are under development: in the *Green Road*, and the *Middle Road 2C*, climate change is limited to 2°C; in the *Middle Road 4C*, and the *High Road* scenarios, global temperature rise reaches 4°C in the 21st century. The trade scenarios build on the Shared Socio-economic Pathways (SSP) scenarios, and on the associated population and GDP forecasts produced by the OECD (Chateau et al., 2012).

The SCC scenarios provide both narratives and detailed economic scenarios of sectoral output for key commodity groups, in 16 regions; inter-regional imports and exports of these commodities; and demand for sea trade, in terms of cargo types – all out to 2050.

The scenarios provide context across different themes of the SCC research project. For example, when modelling future (low carbon) technology uptake as a function of fuel availability and prices, and regulatory incentives, demand may be readily inputted from the scenarios. The scenarios may also provide important insights on their own. For example, energy commodities make up between one third and one half of shipped cargo (UNCTAD, 2015). Limiting climate change to 2°C implies significant shifts in the energy mix, with clearly important ramifications for the shipping sector.

The process of scenario development itself serves to explore plausible futures, allowing for fleshing out some aspects in more detail that may be of particular interest. This paper builds on the SCC scenarios *Green Road* (associated with SSP1) and *High Road* (associated with SSP5) to work out an interlinked couple of climate change impacts, adding richness to the scenarios and providing insight into how to address the threat of climate change impacts, characterised by great uncertainty.

3. A concept of climate change impacts on the shipping sector

In a previous paper (Traut et al., 2015), a categorisation of climate change impacts on the shipping sector has been set out. Generally, risks to (and opportunities for) the shipping sector are subject to various types of uncertainty. For example, Earth system models calculate the climate response to increased atmospheric greenhouse gas concentrations – a result that comes with a level of uncertainty that typically increases together with the resolution at which the response is checked. Of course, future trajectories of atmospheric greenhouse gas levels are determined, at least in part, by man-made emissions – a different type of uncertainty.

In (Traut et al., 2015) climate change impacts are conceptualised as causal chains composed of various links. It is our hypothesis that some of the most important[1] climate change impacts are complex – i.e. they are composed of many causal links. The categorisation is useful because the various links are subject to different types of uncertainty; and because they are amenable to different tools of analysis.

In this study, we put this conceptualisation of climate change impacts to use, presenting two case studies of climate change impacts that are linked together. The first estimates growing dependency on grain imports of two countries, Egypt and Nigeria. The second assesses implications for the ports of Alexandria in Egypt and Lagos in Nigeria, in terms of the expansion of port area required to deal with increased imports, and the need to adapt to rising sea levels.

4. Impacts on grain demand, production, and trade in Egypt and Nigeria

To explore how climate change impacts on crop yields and, together with other drivers –such as changing diets and population growth–, may force or exacerbate countries' dependency on imports to meet demand for staple foods, this scenario analysis focuses on Egypt and Nigeria, the largest and third largest importers, respectively, of cereals in Africa, in 2010. Both countries are important in terms of trade but face contrasting challenges in maintaining food security. Egypt enjoys comparatively high yields whilst the cultivable land is constrained, while the opposite holds for Nigeria.

Development of import dependency is estimated from future scenarios for production and consumption:

- Future changes to harvested area and yield determine production
- Trends in population and per capita demand determine consumption

Per capita demand for cereals is comprised of cereals for food, animal feed, and industry use, and waste. Two contrasting scenarios are developed, within the following contexts of climate change and socio-economic development:

- 2°C warming, stagnant per capita consumption, high climate change adaptation

[1] Use of the term 'important' here is somewhat loose. Broadly, the implied meaning would follow the definition of 'dangerous' given in the IPCC's Fourth Assessment Report (IPCC, 2007), adapted to the term important, and applied to the shipping sector.

- 4°C warming, growing per capita consumption, high climate change adaptation

These elements are corresponding to the Green Road and the High Road scenario, respectively. It is assumed that the average ratio between exports and production is maintained. The scenarios express, and contrast with each other, SSP1 and SSP5 through shared elements (such as meeting challenges to climate adaptation) and elements that are distinct (resource use, population, sustainability narrative).

For Egypt, specific climate impacts are estimated following Yates et al. (1998). They give a percentage change (relative to 1990 yields) to each of the main cereal crops in Egypt in response to: different climate change scenarios (2°C, 3°C, 5°C increase); and the presence or lack of climate adaptation measures. Here, an overall reduction in Egyptian cereal yields (by 2050) is estimated from crop specific yield reduction estimates weighted by the proportional contribution of each crop to production in 2010. This amounts to a 5% yield reduction in the 2°C scenario, and a 13% yield reduction in the 4°C scenario (the latter taken as the mean between 3°C and 5°C). The majority of Egyptian cultivation relies on the river Nile for irrigation. In the 2°C scenario, by 2050, total current cultivatable area is used for grain. In the 4°C scenario, a reduction in rainfall will constrain production and cultivated area remains static, at the 2010 level, out to 2050.

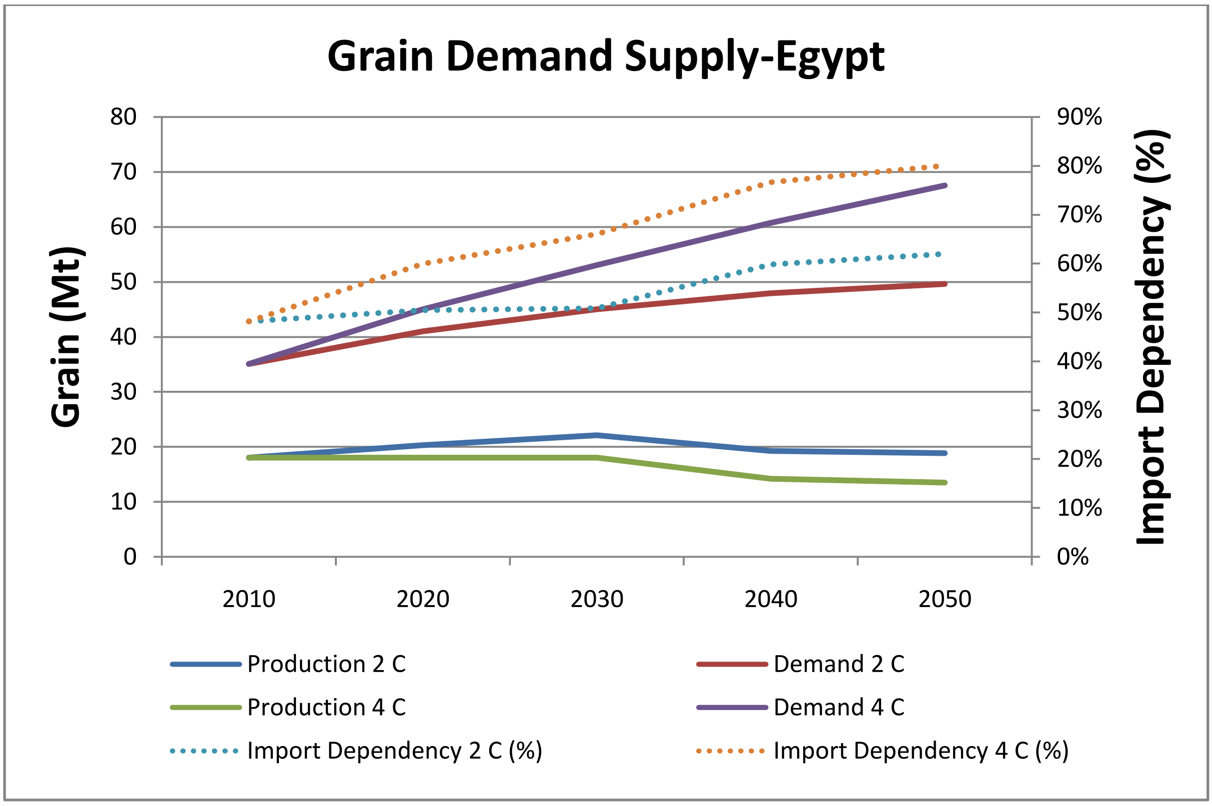

Figure 1. Egypt: projections of production of and demand for grain (left axis), and net share of imports of supply meeting demand (right axis), over the period 2010-50, under contrasting 2°C and 4°C scenario.

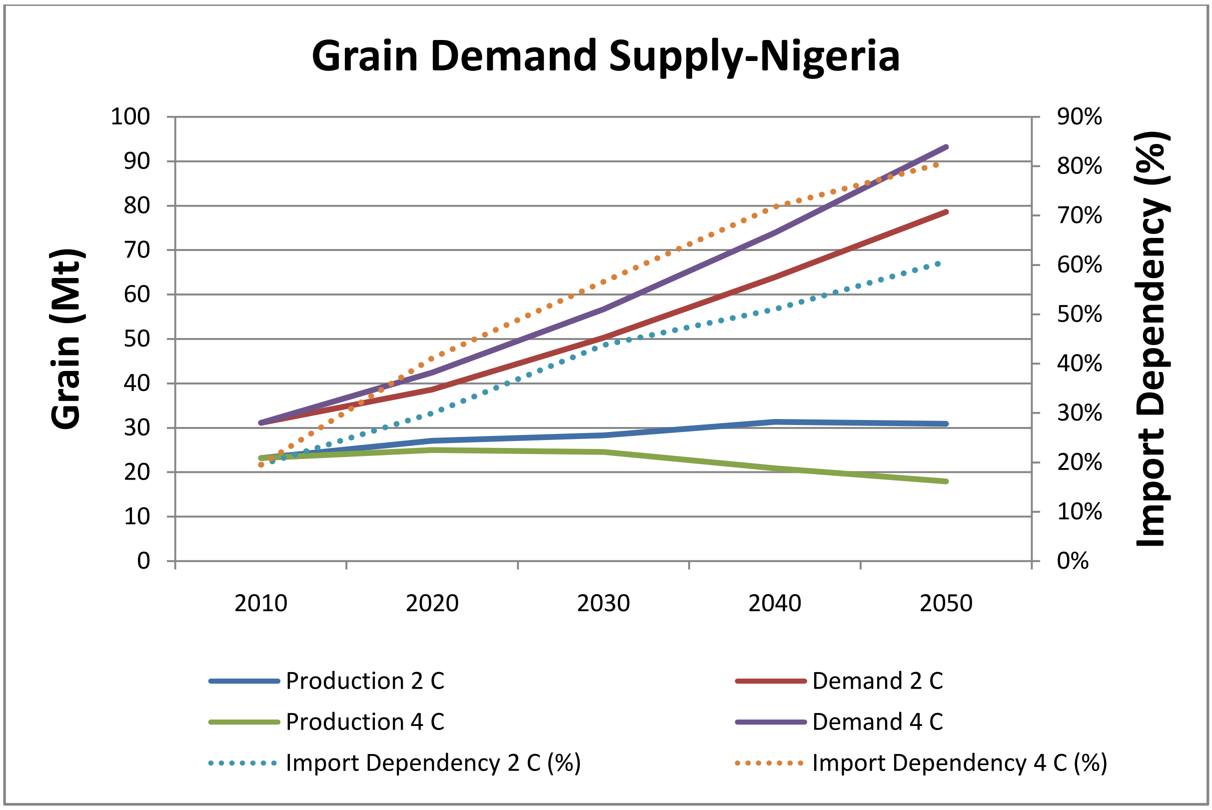

Figure 2. Nigeria: projections of production of and demand for grain (left axis), and net share of imports of supply meeting demand (right axis), over the period 2010-50, under contrasting 2°C and 4°C scenario.

For Nigerian yields, the estimated impact of climate change is based on Roudier et al. (2011) who project relative reductions in yield for West African crops by 2050, consistent with different SRES scenarios, excluding the CO_2 fertilisation effect. By 2050, crop yields decrease by 7% in the 2°C scenario (corresponding with SRES B2); and by 15% in the 4°C scenario (corresponding with SRES A1FI; and moderated from a 20% reduction to account for adaptation measures, with adaptation effects as in (Yates et al., 1998). Recent growth in cultivated land continues in the 2°C scenario, leading to a 50% increase by 2050 in land used for growing cereal crops, while area used remains constant in the 4°C scenario.

In the 2°C scenario, per capita consumption remains constant in both countries while, in the 4°C scenario, per capita consumption maintains observed growth trends in Egypt and reverts to high levels of growth observed in Nigeria prior to 1990.

Figure 1 (Egypt) and Figure 2 (Nigeria) show the resulting projections of demand and supply for grain, together with the net share of imports required to meet demand, out to 2050. In the 2°C scenario, Egyptian grain production changes only slightly, growing 5%, over the period 2010-50, while Nigerian grain production grows by 33%. In the 4°C scenario, production in absolute terms falls by 25% in Egypt, and by 23% in Nigeria. Growth in demand means that import dependency grows in both scenarios, and in both countries. From a net import share of 19% in 2010, Egypt's import dependency grows to 62% in the 2°C scenario, and to 80% in the 4°C scenario. In Nigeria, the net import share grows from 19% in 2010 to 61% in 2050 in the 2°C scenario, and to 81% in the 4°C scenario.

5. Climate change stresses on ports of Alexandria (Egypt) and Lagos (Nigeria)

The main ports of the two countries considered here are Alexandria in Egypt and Lagos in Nigeria, both of which currently handle a large proportion of each country's international trade. Using a conversion rate (tonnage to area) for cereals from an IPCC report (IPCC CZMS, 1990), the anticipated increase in grain imports by 2050 will require an increase in handling and storage areas for both ports (see Table 1).

This is only increased area for imports of one commodity which, assuming there is a similar growth experienced in other commodities and an equivalent increase in exports, may be assumed to be the minimal amount required by 2050. As both ports are located in densely populated urban areas, strategic thinking will therefore be needed to consider how best to handle the expected increase in area required. Acquiring suitable land, developing other ports within each country or investing in efficiencies/novel handling methods at existing ports could all be appropriate approaches.

Table 1. Increase in ports area needed to handle the potential increase in grain imports

		Port area required (km^2)		Percentage (%) increase in area (2010-2015)
		2010	2050	
Egypt	RCP2.6	0.27	0.48	82
	RCP8.5		0.85	220
Nigeria	RCP2.6	0.1	0.75	685
	RCP8.5		1.18	1140

Over the same period, each port is expected to experience a rise in mean sea levels. The magnitude of the rise is uncertain. But using a global model indicates sea level rise for the Green Road and High Road scenarios to be between 0.4 -0.6m for Alexandria and 0.1- 0.4m for Lagos.

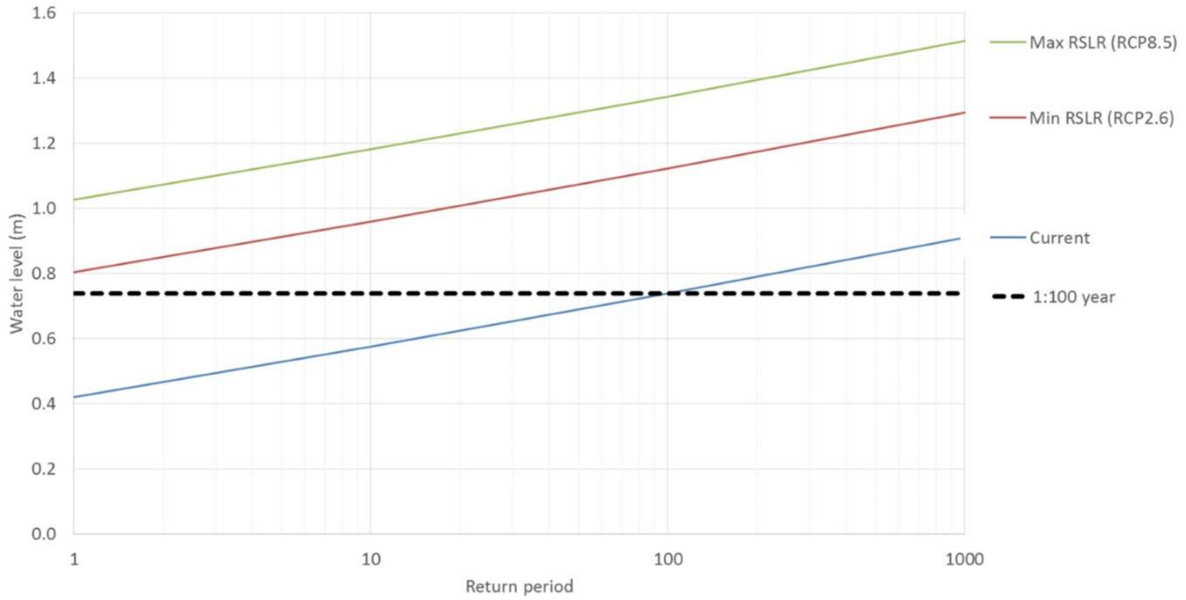

Figure 3. Change in the return period for the 1:100 year water level for Alexandria, Egypt

This rise in mean levels will require working levels to be raised by at least equivalent amounts to ensure port operations will continue. In addition, Alexandria will need to reinforce its protective harbour arm and breakwater structures. The rise in mean levels alone results in the current 1:100 year design water level potentially occurring annually (see Figure 3), so to maintain the current protection standards, a raising of these structure by at least the equivalent of relative sea-level rise would also be required. Potential changes in future storm intensity and frequency in the Mediterranean (e.g. Androulidakis et al., 2015) could increase this requirement.

For the port terminals at Lagos, not being located on the open coast, raising port working levels is probably the more important adaptation. However, any reduction in the return period of storm events could result in changes in the coastal morphology (e.g. Ihenyen, 2003) leading to erosion of the protective barrier islands and sedimentation of approach channels.

6. Discussion

Case studies for Egypt and Nigeria show that both countries' dependency on grain imports may increase significantly, as a result of expected population growth, changes in per capita consumption, constraints in arable land area, and detrimental effects of climate change on yields. Consequently, they will need to generate plans for accommodating this change.

In 2010, Egypt met 48% of its demand for grains with imports. This share could grow to 80% by 2050, in the high climate change scenario considered. In the contrasting high mitigation scenario limiting climate change to 2°C that share still rises to 62%. In absolute terms, grain imports could rise by a factor larger than three. At the same time, Alexandria, one of Egypt's main ports and severely size-constrained, could have to adapt to an 0.4-0.6m higher sea level, with the possibility of today's one in a hundred year water level being experienced annually.

From 19% in 2010, Nigeria's import share of grain demand could rise to 80% in 2050 under the high climate change scenario, and to 61% under the high mitigation scenario, corresponding to a 1140% or 685% increase, respectively, in grain imports. For Lagos, one of Nigeria's major ports that would pose a challenge in terms of required expansion of port area, compounded by an expected sea level rise of 0.1-0.4m.

These results are based on the underlying scenarios. Each of the elements determining the presented results is subject to uncertainty. In some cases, the uncertainty derives from scenario assumptions that are intended to be plausible but cannot be quantified. Examples are the population trajectories of SSP1 and SSP5, or the contrasting –high global temperature increase vs. high mitigation– climate change scenarios. Other uncertainties, e.g. uncertainty in sea level rise, may be amenable to quantification, though they come on top of the uncertainty in the choice of underlying climate (in case of the RCPs: radiative forcing) scenarios. Uncertainty also arises from the omission of potentially important effects, like CO_2 fertilisation in the yield projections for Nigeria. Similarly, there is potential for feedback loops not accounted for in the presented analysis, in particular from adaptation measures. This raises the question of how to make the best use of necessarily imperfect information on climate change risks.

7. Using reports from the lookout

Clearly, climate change has significant implications, in conjunction with other drivers, like population growth and changes in the spatial distribution and volume of commodities, such as those associated with food production. How impacts from climate change will unfold is hard to predict and depends on a multitude of factors. However, the fact that future risks are shrouded in uncertainty does not mean they can be ignored. The scenarios here suggest that even under a more benign projection, some countries are likely to face increasing import dependency, stressing the importance of a functioning and resilient transport system, underpinned by adequate infrastructure. Ports play a crucial role in the shipping system and, with their long life spans their ability to anticipate and adapt to a range of potential climate-related changes is essential in the long term. Even if the scenario process explicitly stresses it does not provide a forecast, there is still an element of probability: the requirement that scenarios be plausible implies that all conceivable outcomes are not equally likely. As a consequence, consideration of a full range of scenarios should inform long-term decision-making and risk assessments, and associated uncertainty should form part of any results. Most importantly, measures taken should ideally be robust with respect to the associated uncertainty. For example, a sustainable measure of increasing grain yields in Nigeria may prove useful in both a high climate impact and a high mitigation scenario. Finally, new findings and unfolding events can be incorporated to ensure the best possible information is used at any point in time.

8. Conclusions

Building on previous work, climate change impacts are conceptualised as causal chains, composed of one or more links. Two links have been presented as case studies. First, projections of the grain import dependency of two countries, Egypt and Nigeria, are given for contrasting climate change scenarios. Second, implications for major ports in these countries, compounded by expected sea level rise, are analysed. For each link, appropriate tools of analysis are applied. In turn, they can be considered as adjacent links in a causal chain, representing a risk from climate change. Together, the case studies demonstrate the use of studying various effects and potential impacts with the tools best suited to the task, while keeping sight of the bigger picture of dangerous threats from climate change – the most important of which may be complex and not be amenable to study through a single lens. As climate change impacts on shipping will become increasingly severe, informed decision-making and building resilience into the system will be crucial.

The presented case studies may also feed into the SCC project scenarios, providing richness of detail, and helping to connect quantitative projections and qualitative narratives.

References

Androulidakis, Y. S., Kombiadou, K. D., Makris, C. V., Baltikas, V. N. & Krestenitis, Y. N. 2015. Storm surges in the Mediterranean Sea: Variability and trends under future climatic conditions. Dynamics of Atmospheres and Oceans, 71, 56-82.

Chateau, J., Dellink, R., Lanzi, E., & Magne, Bertrand. 2012. Long-term economic growth and environmental pressure: reference scenarios for future global projections. Draft presented at the OECD EPOC/WPCID.

Ihenyen, A. E. 2003. Recent sedimentology and ocean dynamics of the Western Nigerian continental shelf and coastline. Journal of African Earth Sciences, 36, 233-244.

IPCC. 2007. IPCC Fourth Assessment Report: Climate Change 2007. Working Group III: Mitigation of Climate Change. 1.2.2.

IPCC CZMS 1990. Sea-level rise: a world-wide cost estimate of coastal defence measures. Appendix D in Report of the Coastal Zone Management Subgroup, Response Strategies Working Group of the Intergovernmental Panel on Climate Change. The Hague, The Netherlands: Ministry of Transport, Public Works and Water Management.

Roudier, P., Sultan, B., Quirion, P. and Berg, A. 2011. The impact of future climate change on West African crop yields: What does the recent literature say?.Global Environmental Change, 21(3), pp.1073-1083.

Traut, M., & Anderson, K. 2014. Report from the SCC's 2°C to 4°C Shipping Workshop. Shipping in Changing Climates working paper.

Traut, M., Hanson, S., Mander, S., & Walsh, C. 2015. Risk, rice, and rising seas – impacts of cliamte change on maritime transport. Shipping in Changing Climates conference, Glasgow, 2015.

UNCTAD, 2015. Review of Maritime Transport 2015.

Yates, D.N. and Strzepek, K.M. 1998. An assessment of integrated climate change impacts on the agricultural economy of Egypt. Climatic Change,38(3), pp.261-287.