



United Nations
Economic Commission for Africa



Economic growth, development and climate change in Africa

A report commissioned by the United Nations Environment Programme (UNEP), the African Development Bank and the United Nations Economic Commission for Africa (ECA) and prepared by Climate Analytics, in collaboration with the Potsdam Institute for Climate Impact Research (Germany), the Centre for Environmental and Resource Economics at Umeå University (Sweden), the Institut National pour la Recherche Agronomique (Morocco), the University of Nigeria-Nsukka (Nigeria), the University of Addis Ababa (Ethiopia), Humboldt University (Germany), the University of Makerere (Uganda) and the University Eduardo Mondlane (Mozambique).

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Acknowledgments: The authors would like to acknowledge the contributions of participants in the kick-off workshop organized at the African Development Bank and in seminars organized at Viadrina University, the International Research Institute for Climate and Society (IRI - Columbia University), the German Institute for Economic Research (DIW-Berlin) and the Fondazione ENI Enrico Mattei (FEEM), colleagues at Climate Analytics, particularly Matthias Mengel, Carl-Friedrich Schleussner and Tabea Lissner, as well as Niklas Roming and Marcia Rocha for programming support. Finally, we particularly thank Abbi Kedir, George Kararach for contributing to further methodological development.

Editorial team: Ela Smith, Cindy Baxter, Michiel Schaeffer, Florent Baarsch, Jessie Ruth Granadillos.

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1. Executive summary

This report assesses economic growth and development risks and opportunities for African countries in two scenarios of future climate changes: **a low, Paris Agreement scenario (well below 2°C)** and **a high-warming scenario (2°C by 2050, exceeding 4°C by 2100)**. It highlights the risks to which African countries are exposed and the benefits of mitigation for economic growth and development.

The report finds that African countries will be severely hit by climate change and weather extremes. Stringent mitigation action would mean that, from as early as 2030, African regions would start experiencing reduced macroeconomic losses.

The report is aimed at providing African decision-makers with more accurate macro-economic indicators and future economic growth trends that take into consideration climate change in adjusting short-term GDP forecasts and long-term projections.

The findings will be useful in informing African countries' national and international processes related to both the implementation of the Paris Agreement on climate change and the United Nations Sustainable Development Goals.

Main findings

1. **The direct and indirect costs of taking action on climate change will be high, but the costs of inaction will be much higher.** For example, with climate change, Western and Eastern Africa could lose up to about 15 per cent of their gross domestic product (GDP) by 2050. Global efforts towards a low-emissions, low-warming scenario – as expressed in the Paris Agreement's long-term goals – could avert a large part of the most serious macroeconomic and development consequences for Africa.
2. **The report clearly demonstrates that there are substantial development risks in Africa under any level of warming.** Uncertainty over the magnitude of warming cannot therefore be used as a rationale to postpone action.
3. Climate change will pose additional constraints and threats to development in Africa in the twenty-first century. Failure to integrate climate change impacts into development planning will result in major economic, social and human development risks.
4. **Actions on climate change in mitigation *and* adaptation will be rewarded by significant benefits and co-benefits in** macroeconomic stability, job creation, and decreased negative impacts of climate change on development.
5. Mitigating emissions in Africa's energy sector would result in 0.7 million net potential jobs in 2030, which would thereafter sharply increase to as many as 11.8 million jobs by 2050.

Key results

1. Without action, climate change would impede development across Africa.

African countries' limited resilience against the negative impacts of today's climate are already resulting in lower growth and development, highlighting the consequences of an adaptation deficit. Indicative findings show lower GDP per capita growth ranging, on average, from 10 to 13 per cent (with a 50 per cent confidence interval), with the poorest countries in Africa displaying the highest adaptation deficit. Climate change will exacerbate the high vulnerability, and limited adaptive capacity, of the majority of African countries, particularly the poorest – potentially rolling back development efforts in the most-affected countries.

I. Climate change and climate variability could lead to severe macroeconomic consequences as early as 2030.

- In all African regions, negative climate change impacts would progressively compound and lead to decreasing GDP per capita. The warming scenarios entail losses by 2030 (as compared to a baseline GDP per capita scenario) that range from -0.6 per cent in Northern Africa in the low-warming scenario, to -3.6 per cent in Eastern African in the high-warming scenario.
- As early as 2030, African regions would start benefiting from stringent mitigation action. Even though, by 2030, the absolute difference in losses between the low and high warming scenarios is still minor, the high-warming scenarios lead to increased damage ranging from about 16 per cent in Northern Africa to about 54 per cent in Central Africa, compared to losses in the low-warming scenario.

II. African countries are projected to experience detrimental macroeconomic consequences from climate change by mid-century, in both warming scenarios.

- Under a high-warming scenario, Eastern and Western Africa, would experience a reduction in GDP per capita by about 15 per cent by 2050 (below a baseline GDP scenario).
- Northern and Southern Africa would experience a decrease in GDP per capita approaching 10 per cent by 2050, while Central Africa could be less affected, with a possible decrease of 5 per cent in the high-warming scenario.
- After the 2030s, the loss gap between the low- and high-warming scenarios widens substantially. By 2050, losses in the high-warming scenarios range from 50 per cent higher for Central Africa, to around 85 per cent higher for Western African regions.
- A limited number of African countries, including Liberia, the Sudan and the United Republic of Tanzania, display the highest economic vulnerability to future climate change, in both warming scenarios. This high economic risk is the consequence of both high historical vulnerability and rapidly changing temperature and precipitation patterns.

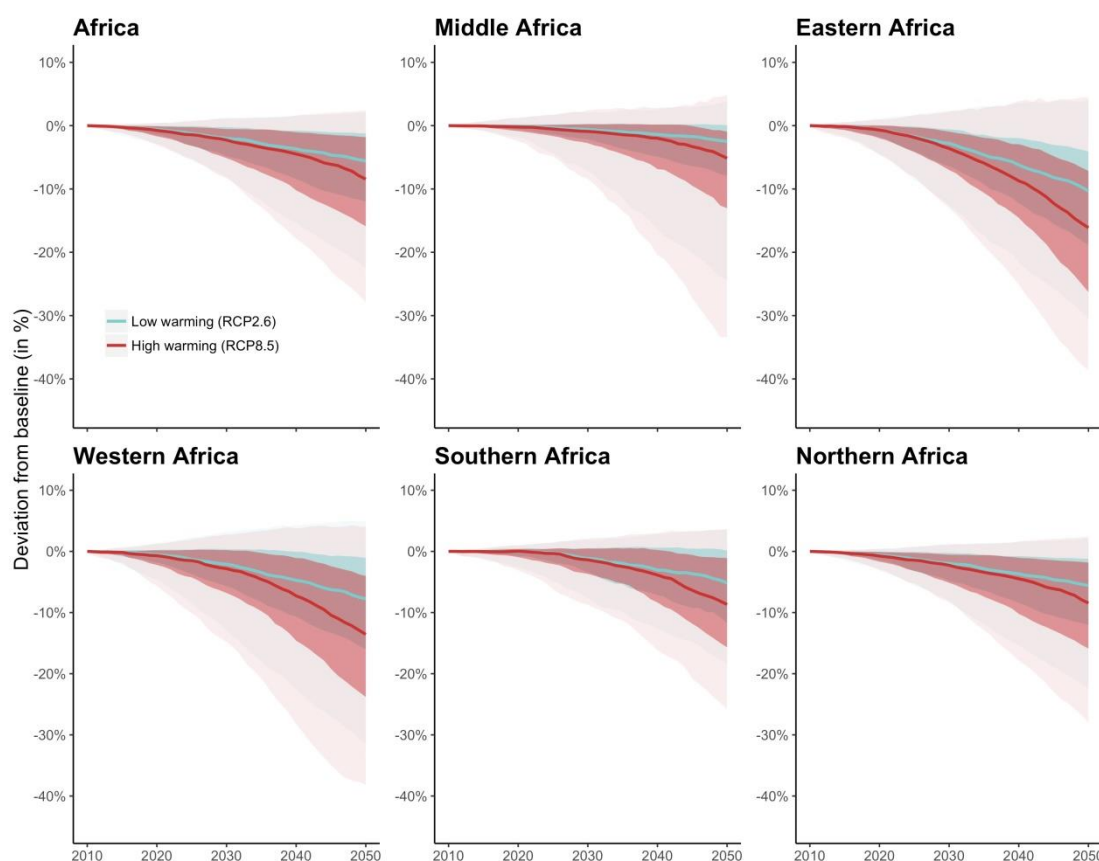
Table 1 Five most-affected countries¹ in 2030 and 2050 and associated median change in GDP per capita (in per cent change as compared to a baseline scenario) in the low- and high-warming scenarios.

2030				2050			
Low warming		High warming		Low warming		High warming	
Country	Change in GDP per cap. (in %)	Country	Change in GDP per cap. (in %)	Country	Change in GDP per cap. (in %)	Country	Change in GDP per cap. (in %)
Morocco	-4.5	UR Tanzania	-6.0	Sudan	-12.7	UR Tanzania	-18.6
Sudan	-4.4	Sudan	-4.9	UR Tanzania	-11.4	Sudan	-18.6
UR Tanzania	-4.1	Liberia	-4.8	Liberia	-11.0	Liberia	-16.9
Liberia	-3.5	Morocco	-4.5	Guinea-Bissau	-10.7	Guinea-Bissau	-16.7
Mauritania	-3.0	Kenya	-4.4	Morocco	-10.3	Mauritania	-16.4

- III.** The occurrence of climate extremes would lead to increased government expenditure and a reduction in the volume of collected taxes, ultimately resulting in a **possible increase in government debt**.
- IV.** The increasing negative impacts of climate change on both the GDP per capita and the development capacity of African countries could reduce Africa's ability to cope with – and adapt to – the current and future impacts of climate change. Countries could be increasingly drawn into a **downward spiral of risks and vulnerabilities**.

¹ The five most-affected countries for each scenario and time period are selected among the countries for which the mean absolute percentage error is lower than 10 per cent and the ensemble size for the model calibration is above 10 years.

Figure 1 GDP per capita changes resulting from continued global warming for all African countries (top-left panel) and countries in the five regions from 2010 over the next three decades, in a low-warming scenario (in blue) and a high-warming scenario (in red). The shaded ribbon represents the 50 per cent statistical confidence interval, while the light shaded interval represents the 95 per cent interval.



2. While adapting to – and coping with – climate change will cost less under lower levels of warming, African Governments will still face residual damages with considerably higher costs, and those costs will rise substantially with more warming.

- Owing to African countries' current adaptation deficit, adapting to climate change will necessitate closing the existing adaptation deficit, including improved territorial and city planning, better agricultural practices or updated building codes, etc. Leaving the current adaptation deficit unchecked will lead to significantly higher losses and vulnerabilities.
- Given the limits to adaptation, for all African regions, the costs of residual damages are projected to be around five times higher than adaptation investments and costs combined. This reinforces the need for robust and binding global mitigation efforts, and an adequate provision for a loss and damage mechanism to deal with residual damages.
- The total costs of both climate change adaptation and residual damages are at least one third higher in the high-warming scenario, and, in Eastern Africa, will double by mid-century.

3. The range of benefits from taking action go well beyond intended, climate-related targets

- Adaptation protects communities and creates jobs. Adapting to climate change – even if warming is kept within the limits indicated in the Paris Agreement – will still require high costs, although they would be largely outweighed by the benefits. For example, in the high-warming scenario, by 2050, adaptation benefits are about five times greater than the costs in the health sector. The implementation of adaptation measures would also lead to skilled and unskilled job-creation in a wide range of economic sectors, including construction, health and services.
- Mitigation limits climate change impacts and damages. By 2030, the low-warming pathway would cost sub-Saharan African countries between a tenth (in Northern Africa) and a third (in Central Africa) less than macroeconomic losses projected to be incurred in the high-warming scenario. This difference almost doubles by 2050, from being a third higher in Northern African (compared a tenth in 2030) to almost 85 per cent higher in Western Africa.
- Mitigation leverages development. Mitigation actions are also associated with at least three direct co-benefits: increased energy security, employment generation, and reduction in health risks related to direct exposure to pollution from fossil-fuel combustion.

Recommendations

1. To mitigate the negative impacts of development and economic growth, African Governments should integrate climate change risks in development and macroeconomic planning. Practically, this could be pursued through the following actions:
 - (a) An improved understanding and knowledge of current aggregate and sectoral economic vulnerability are urgently needed to address countries' adaptation deficit in the most meaningful manner;
 - (b) Macroeconomic forecasts for Africa should include climate-induced economic risks. This integration would require capacity-building and analytical tools for government experts to analyse climate and socioeconomic data, and collaborate across ministries and agencies (development planning, statistics, meteorology, etc.);
 - (c) Multisectoral processes within Governments should lead to the design and implementation of resilience-building measures at the sectoral level. Development investment projects in Governments' mid-term development plans should integrate resilience-building measures for all prioritized development sectors.
2. In planning and implementing development policies, it is important to consider the benefits and co-benefits for both mitigation and adaptation actions. Climate-informed and climate-resilient development planning is essential to mitigate the future negative impacts of climate change.

3. While investments in adaptation would benefit communities, some African Governments will simply not be able to afford them. It is essential that they receive adequate support in accessing international finance through bilateral and multilateral sources such as the Green Climate Fund, mobilize domestic public and private sources, explore opportunities from additional private sector sources and innovate financial mechanisms.

African Governments, together with technical and financial partners, need actively to promote renewable energy and energy efficiency through investment incentives for the development of low-carbon economies.

2. Technical summary

Economic growth and development across Africa are intrinsically connected to climate variability and change. While in 2015 many significant international processes bore fruit, such as the Paris Agreement under the United Nations Framework Convention on Climate Change, the United Nations agreements on Sustainable Development Goals and the Sendai Framework for Disaster Risk Reduction, the years leading to 2020 see an urgent need to assess these topics together. Owing to the current and future development needs of Africa, it is imperative to appraise how the interconnectedness of these agreements will shape its future.

This report seeks to contribute to the national and international processes related to these agreements, and in particular the post-Paris implementation phase at both national and international levels, such as those related to nationally determined contributions (NDCs), national adaptation plans (NAPs) and long-term low greenhouse gas-emission development strategies. The report explores the challenges that climate change presents for Africa – from both a macroeconomic and a development perspective; and from a continental to a national scale. It also assesses the benefits of proactively addressing these challenges; and the potential costs of not doing so. The principal aim is to provide economic, finance and planning decision-makers with better assessment tools and information on the economic consequences of climate change and potential risks to development prospects.

The core analyses in this report are rooted in empirical climatological and socioeconomic evidence in five regions on the macroeconomic scale (Northern, Eastern, Southern, Central, Western Africa), complemented by five country case studies (Morocco, Ethiopia, Mozambique, Nigeria and Togo).

The report assesses the economic and development risks and opportunities in two scenarios of future climate change.

- In the low-warming scenario,² the increase in global mean temperature reaches about 1.6°C above pre-industrial levels by 2050, and stays around that level throughout the rest of the century, consistent with “well below 2°C” mentioned in article 2 of the Paris Agreement.
- In the high-warming scenario,³ temperature increase exceeds 2°C by 2050, continues to rise and exceeds 4°C by the end of the century.

Four key pieces of new research allow the report to deliver a broad overview of the economics of climate change across Africa.

- First, a careful assessment has been made of the non-linear effects of local temperature and precipitation changes on GDP growth, allowing an estimate of the effects of increased or decreased frequency of extreme climate events for the next decades.
- Second, a new integrated assessment model – AD-AFRICA – integrates recent climate change impact literature for Africa, divided into these five regions, with recent modelling advances. This allows for subregional differentiation for

² The low-warming scenario used in this report is the IPCC RCP2.6 scenario.

³ The high-warming scenario used in this report is the IPCC RCP8.5 scenario.

assessing how global mitigation and national/regional adaptation options combine to reduce damage.

- Last, in a scenario consistent with a warming kept below 2°C by 2100, mitigation action in the energy sector would lead to lower job creation in the oil, gas and coal subsectors but would be completely offset by gains from renewable energy sources, including nuclear energy. Mitigating emissions in the energy sector in Africa would result in a net potential employment of 0.7 million in 2030 and sharply increase thereafter to as high as 11.8 million by 2050.

Also for the first time, in analysing the interconnectedness of climate change impacts on economic development, adaptation costs and its benefits as well as the opportunities and benefits from taking action on climate change, this report provides a uniquely African focus. As high as will be the direct and indirect costs of taking action on climate change, the costs of inaction will be even higher.

This report clearly shows that Governments and decision-makers who take action on climate change – through mitigation and resilience development – will be rewarded by significant benefits and co-benefits.

2.1 Large economic and development impacts

If no action is taken, climate change would impede development across Africa on a macroeconomic scale. This conclusion is derived from direct, quantitative evidence grounded in empirical data.

Climate change risks to economic growth

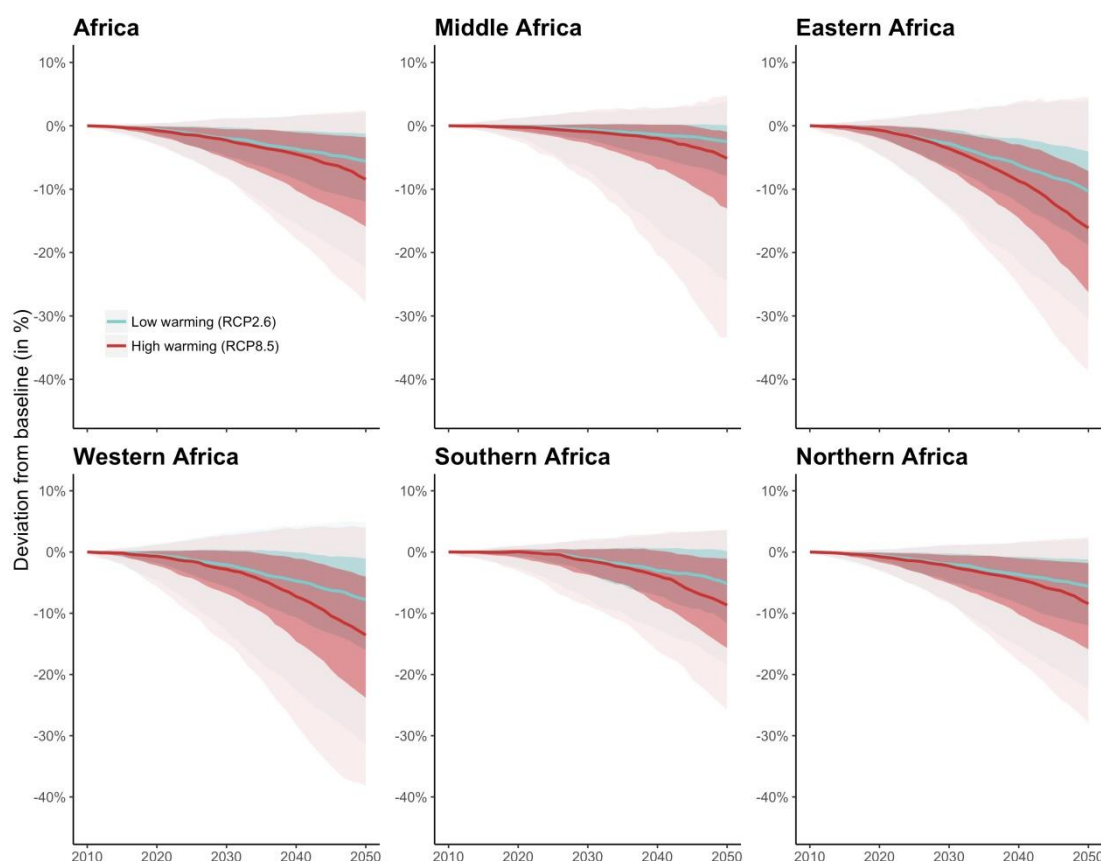
- African countries' limited resilience against the negative impacts of today's climate are already resulting in lower growth and development, highlighting the consequences of this lack of resilience and adaptive capacity. Indicative findings show lower GDP per capita growth ranging, on average, from 10 to 13 per cent (with a 50 per cent confidence interval), with the poorest countries in Africa displaying the highest adaptation deficit.
- African countries are projected to experience clear detrimental macroeconomic consequences from climate change over the coming decades. Across Eastern and Western Africa, climate change in the high-warming scenario would reduce GDP per capita by around 15 per cent by the 2050 (below a baseline GDP per capita scenario).⁴ Northern and Southern Africa would also be seriously affected, with around a 10 per cent decrease in GDP by 2050, while Central Africa would be comparatively less affected, with a possible decrease of 5 per cent in the high-warming scenario (figure 2.1).
- A globally low-emissions, low-warming scenario, in line with the Paris Agreement's goal of limiting global warming well below 2°C and pursuing efforts

⁴ This total decrease in GDP corresponds to annual GDP growth being structurally lower by 0.7–1.0 per cent on average during the 2015-2049 period.

to limit the temperature increase to 1.5°C above pre-industrial levels, could avert a large part of the most serious macroeconomic consequences for Africa.

- As early as 2030, a gap in macroeconomic costs emerges between a low and a high-warming scenario, highlighting the necessity to avoid a high-emissions, fossil-fuel-intensive trajectory. By 2050, losses in the high-warming scenarios range from 50 per cent higher for Central Africa, to around 85 per cent higher for Western African regions.
- With climate-related disasters expected to slow GDP per capita growth, African Governments are likely to experience increasing pressure on budgets and fiscal balances. The Ethiopian case study, and the broader scientific literature, shed light on the fiscal consequences of climate-related disasters, such as the occurrence of extreme dry and wet conditions and high temperatures. Climate extremes could lead to increased government expenditure, a reduction in the volume of collected taxes, ultimately resulting in an increase in government debt. Additional evidence on these budgetary implications and their long-term effects is needed, but these initial findings show that the increased negative consequences of climate-related disasters for fiscal balance and government budgeting should, at the very least, be considered plausible, if not likely.

Figure 2.1 GDP per capita changes resulting from continued global warming for all African countries (top-left panel) and countries in the five regions from 2010 over the next three decades, in a low-warming scenario (in blue) and a high-warming scenario (in red). The shaded ribbon represents the 50 per cent statistical confidence interval, while the light shaded interval represents the 95 per cent interval.



Benefits and risks to structural change

- Using Northern Africa as an example, the report finds that structural change⁵ could decrease countries' economic vulnerability to precipitation and temperature as compared to current conditions. Similarly, countries' sensitivity to extreme dry events could significantly subside as the share of agriculture decreases in GDP. However, while structural transformation is highly recommended to foster economic development, the analysis also shows that the services and industry sectors have higher sensitivity to extreme wet events than the agricultural sector (due, for example, to business disruption in the aftermath of floods). As a result, with structural transformation, macroeconomic sensitivity to extreme wet events could slightly increase.
- The analysis on Northern African countries reveals that countries projected to be exposed to more extreme wet events as a consequence of climate change, could experience higher macroeconomic risks with structural change than without, if no adequate adaptation and risk management measures are implemented. This

⁵ Macroeconomic process characterized by a decreasing share of agriculture in the GDP to the advantage of services and industry.

preliminary analysis suggests that structural change under a changing climate must go hand-in-hand with infrastructural improvements that increase resilience of industry and services to extreme wet events, such as better drainage systems, alternate routes, improved urban planning, etc. Above all, it underlines that policymakers need to account for their countries' dynamic economic structure to ensure the long-term success of adaptation and risk-management strategies.

Combined GDP growth and development risks

- The increasing negative impacts of climate change on both the GDP per capita and the development capacity of African countries could reduce Africa's ability to cope with – and adapt to – the current and future impacts of climate change. Countries could be increasingly drawn into a **downward spiral of risks and vulnerabilities**.
- A decreased ability of Governments and households to invest in adequate protection to adapt to long-term changes in precipitation and temperature, or in emergency relief, could further amplify the future negative consequences of climate change. This decreasing ability, combined with the increasing severity of the impacts of climate change in Africa, could heighten the likelihood of countries falling into macroeconomic low growth patterns, or poverty traps, potentially leading to increasing their dependency on international support.
- Climate change impacts on GDP growth would be an additional constraint on African Governments' capacity to reach the 2030 Sustainable Development Goals agreed by the United Nations in 2015, possibly hindering them from reaching the targets if impacts were left unchecked.
- Our analysis of the effects on both GDP per capita by 2030 indicates that many African countries would have already experienced negative consequences for their GDP.
 - In the high-warming scenario especially, countries in Eastern and Southern Africa would have a GDP up to 3.6 per cent lower than their GDP per capita baseline scenario.
 - Reduced GDP per capita prospects, as a consequence of climate change, could have implications for a wider range of social and economic indicators relevant to the Sustainable Development Goals, such as education, health access and above all poverty eradication.
- The combined development and macroeconomic risk to attaining these Goals highlights the need for African countries to adopt early and efficient development resilience planning. With the added risk to GDP, this also highlights the pressing need to integrate climate change impacts as a constraint in development planning.

2.2 Adaptation and resilience dividends

Adapting to – and coping with – climate change will cost less with lower levels of warming. The damages that remain after implementing adaptation would still be

considerably higher than adaptation costs, even more certainly in the high-warming scenario.

- A high-warming scenario will bring high adaptation costs in all African regions, particularly in Eastern and Western Africa. The new integrated assessment model AD-AFRICA's recent modelling advances incorporate recent climate change impact literature for Africa, divided into five regions.
- In 2050, adaptation investment needs in Eastern Africa would range between 0.3 per cent of the gross regional product (GRP) in a low-warming scenario, and 0.6 per cent in high-warming scenarios. In the same scenarios, this cost would reach 0.3 and 0.4 per cent per year of GRP in Western Africa. This is a conservative estimate, given the limited number of sectors with quantitative data available for this kind of assessment.

Despite high adaptation costs, and even when assuming very efficient adaptation measures, residual damages would remain high, and would continue to affect communities and economies. For all African regions, the damages after implementing adaptation, or residual damages, are projected to be about five times higher than adaptation investments and costs combined (

Figure 2). High residual damages highlight the limits to adaptation and thereby reinforce the need to limit warming via strong global mitigation efforts, as well as the need to set up an adequate loss and damage mechanism at both the African and international levels – to deal with residual damages.

- For all African regions, total climate change costs, which include adaptation costs and residual damages, are projected to be significantly higher in the high-warming scenario than in a low-warming world. Total costs are at least one third higher in the high-warming scenario, and up to twice as high in Eastern Africa (
- Figure 2).

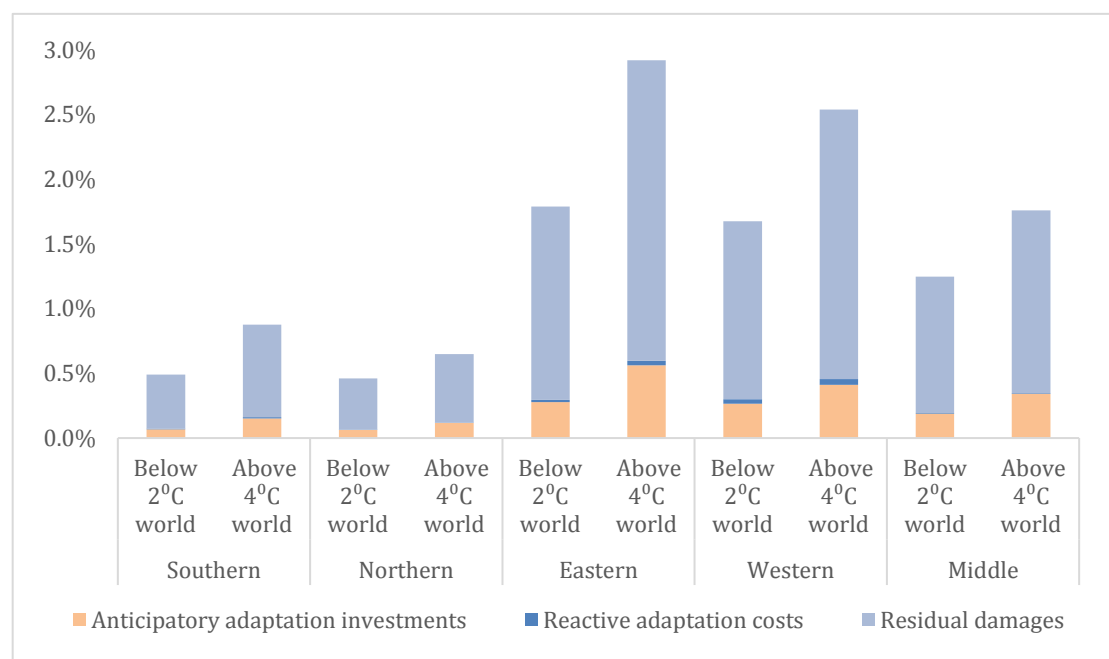


Figure 2 Total net damages for five African regions: residual damages, anticipatory adaptation investments (by the public sector) and reactive adaptation costs (by the private sector) in 2050 for each region for a scenario holding global warming below 2°C (low-warming scenario) and a scenario exceeding 2°C by 2050 (high-warming scenario) and heading towards above 4°C by 2100, as percentage of regional GDP in 2050

- Current and future household adaptive capacity and resilience is one of the determinant factors of future adaptation costs in Africa. A detailed assessment of the effects of climate-related disasters (droughts and floods) in Mozambique on agricultural households sheds light on two important pieces of information to guide adaptation processes.
 - First, rural households are highly vulnerable to the consequences of climate-related disasters, more than urban households.
 - Second, socioeconomic factors strongly increase vulnerability, such as whether households are headed by women, or have limited ownership of transportation and communication means, which in turn influences households' adaptive capacity.
 - Adaptation measures designed to prioritize the poor and most vulnerable could cost even more than current estimates, further raising the need for adaptation finance.

2.3 Yielding the benefits of taking action

The range of benefits of taking action go well beyond intended climate-related targets that reward both the global community and the specific countries initiating and implementing climate policy. Mitigation and adaptation actions will contribute to creating jobs and improving socioeconomic conditions, in line with broader development goals such as the Sustainable Development Goals and national strategic plans.

Adaptation protects communities and creates jobs

- Adapting to climate change will bring high costs, both in the low-warming – and particularly in the high-warming – scenarios. However, adaptation costs and investments would be largely outweighed by the benefits of reducing countries' future climate change costs and negative macroeconomic and development consequences. Adaptation benefits range from seven times the costs in the health sector to 24 times the costs in the road infrastructure sector in 2050.

Figure 3 Costs (dark coloured bars) and benefits (light coloured bars) of adaptation in five African regions in 2010, 2030 and 2050 in the high-warming scenario, exceeding 2°C by 2050 and heading towards above 4°C by 2100, in billion US\$ (Purchasing Power Parity).



- This report's detailed analysis of climate change action in Togo over recent years highlights the direct and indirect employment benefits from implementing adaptation measures.
- Further investment in adaptation activities was estimated to be associated with large job creation in the service sector and even larger in the infrastructure sector. Over the 2010–2014 period, adaptation (and mitigation) projects, such as ecosystem-based adaptation projects, implemented by the Togolese Government accounted for 0.3 per cent of the working population and 2.2 per cent of the working population in the infrastructure sector.
- With future needs for adaptation increasing in the coming years and decades, benefits from implemented actions would also progressively grow. For instance, faster job creation will positively contribute to development and poverty eradication planning.

Mitigation limits climate change impacts and damages while leveraging development

- The comparison of macroeconomic and development consequences as well as adaptation needs between the low- and high-warming scenarios calls attention to the role of adequate mitigation at the global level in line with the provisions of the Paris Agreement. By 2030, the low-warming pathway would cost sub-Saharan African countries from a tenth (in Northern Africa) to a third (in Central Africa) less than macroeconomic losses projected to be incurred in the high-warming scenario. This difference almost doubles by 2050, from being a third higher in Northern African (as compared to a tenth in 2030) to almost 85 per cent higher in Western Africa.
- The research conducted for this report also highlights the negative economic impacts of the high-warming scenario as compared to the low-warming scenario, and would start affecting African country economies as early as the 2020s–2030s. This very early onset of negative consequences of the high -warming scenario is even earlier than previously estimated in other studies. The high-warming scenario’s early-onset risk reinforces the need for stringent mitigation action pre-2020 and pre-2030 to limit the negative impacts of unchecked emissions as early as possible.
- In addition to decreasing the cost of climate change in Africa (and globally), implementing mitigation measures, for example as communicated under the United Nations Framework Convention on Climate Change in Governments’ intended national determined contributions (INDCs), would also yield direct development co-benefits at the country level. Mitigation actions in Africa are associated with at least three direct co-benefits: increased energy security, employment generation, and reduction in health risks from exposure to air pollutants associated with emissions.
 - Energy access is one of the main development challenges for Africa in the twenty-first century, and energy demand is expected to still increase by 80 per cent between 2010 and 2040. The implementation of additional mitigation policies post-2020 and in line with the low-warming scenario is projected to improve energy security by increasing the capacity of domestic production, net of exports. The share of demand covered by domestic production in the low-warming scenario is 1.5 times higher in 2030 and twice as high in 2050 than in a scenario in which no additional mitigation would be implemented after 2020. This improvement is attributed to an increase in renewable energy production and energy efficiency, as well as lower consumption of fossil fuels.
 - The change in the projected energy mix from the expansion of renewable energy and other sources (e.g., nuclear, biomass, hydro, wind, solar and geothermal energy) also leads to changes in the employment structure within the energy sector. While a reduction in employment in electricity generated from fossil fuels is projected, these lost jobs are completely offset by gains in other sources, resulting in a net potential employment of 0.7 million in 2030, sharply increasing thereafter to as high as 11.8 million by 2050.
 - Stringent mitigation action would also result in a reduction in the risk of respiratory and cerebro-cardiovascular diseases induced by exposure to fossil

fuel and traditional biomass emissions, as seen in the lower projected premature deaths in Africa.

2.4 Road to implementation

The year 2030 is a symbolic one for both climate action and limiting the global temperature rise following the Paris Agreement, and is also the target year for meeting the Sustainable Development Goals (SDGs).

As of the 2 May 2016 synthesis report of the United Nations Framework Convention on Climate Change,⁶ there have been 161 Intended National Determined Contributions (INDCs) of 189 Parties communicated, by which the aggregate global emission level would be reduced to 55.0 Gt CO₂eq. in 2025 and 56.2 Gt CO₂eq. in 2030. From the countries that submitted INDCs, 20 countries,⁷ which are predominantly small and vulnerable, have moved towards finalizing and registering their NDCs. While the targets may be clear, the road to implementing climate action often presents challenges, not only by limited resources, but also in terms of the capacity to contextualize large goals into smaller, more concrete steps. For instance, Ghana alone estimates US\$22.6 billion in investments needed to finance a 10-year post-2020 climate action plan.⁸ Furthermore, there must be a synergy between environmental, economic, and social considerations; otherwise, actions may result in ineffective, or even contradictory policies that create trade-offs between climate action and poverty reduction.

The models developed in this report and the key takeaways serve as a springboard for individual countries in creating climate change adaptation, mitigation and development plans that are economically, environmentally, and socially sound:

- (a) Given limited resources, sectoral forward-looking risk analyses, such as presented in this report, may be downscaled to country and subnational levels to provide a scientific basis for investment prioritization based on the likelihood and magnitude of the occurrence of climate-related events, economic sensitivity, and different levels of development experienced subnationally. This information is also useful for updating existing national climate change plans, addressing within-country inequality issues magnified by the impacts of climate change, and complementing existing in-house macroeconomic models of the government planning ministries.
- (b) Development risk indicators help align environmental changes and climate action with development plans and the Sustainable Development Goals, therefore allowing for an outcome-based monitoring of the effectiveness of adaptation policies, given the projected risks of future climate-related extremes.
- (c) The costs of unpreparedness to climate change and the benefits of taking action provide an essential economic and social justification for individual countries, particularly developing countries, to have access to needed increased financing,

⁶ <http://unfccc.int/resource/docs/2016/cop22/eng/02.pdf>.

⁷ <http://www4.unfccc.int/ndcregistry/Pages/All.aspx>.

⁸ http://www4.unfccc.int/Submissions/INDC/Published%20Documents/Ghana/1/GH_INDC_2392015.pdf.

as well as to technical support and capacity-building for assessing risks and streamlining policies from national to local levels.

- (d) The important synergies between mitigation and adaptation actions, some of which are highlighted in this report, can aid policymakers to consider undertaking both categories of climate action intensively, so that concerted efforts to move towards a low-warming scenario can significantly lower the amount of adaptation efforts required to reach a resilience level that prevents unmanageable loss and damage.

2.5 Outlook: enabling and informing decision-makers

- Although the magnitude of the future economic impacts of climate change is still under discussion within the scientific community, such impacts are inevitable in Africa. This report clearly shows that any degree of warming carries economic and development risks. Uncertainty over the magnitude of warming can therefore not be used as a rationale for postponing action.
- These constraints have to be integrated in policymaking and development planning, in combination with implementing adaptation and mitigation measures. This report shows that failure to integrate and adapt the impacts of climate change to the country's development planning will result in severe development and macroeconomic risks. The report proposes a number of recommendations to strengthen African countries policymakers' capacity to design climate-resilient development plans:
 - (a) Publications supporting macroeconomic forecasts such as the African Economic Outlook, published every year by the African Development Bank, could integrate a five-year and longer-term update on climate-induced macroeconomic risks to which countries are expected to be exposed.
 - (b) Capacity-building is needed for experts in statistical and meteorological offices so that they can more effectively combine and analyse climate and socioeconomic data. Collaboration between these offices and the ministry in charge of planning and forecasting could also be strengthened.

To prevent future climate-related disasters from having permanent impacts on the communities' development capabilities, the report recommends that:

- (c) Financial instruments to support households in the aftermath of climate-related disasters as well as in the recovery phase should be scaled-up. To maintain households' development capabilities in the aftermath of disasters and the recovery phase, transfer mechanisms (involving cash or food) could be associated with development conditions, such as mandatory school attendance to limit the risks of school drop-out or regular medical check-ups and vaccinations to circumvent epidemic risks. Before scale-up, these mechanisms would need to be experimented using state-of-the-art methods.

Anticipatory and reactive adaptation investments will generate benefits for communities in avoiding the detrimental impacts of climate change; however, they will come at a cost that a number of countries may not be able to face. Therefore, the report recommends:

- (d) Fostering international support from multilateral sources (e.g. Green Climate Fund) and bilateral sources; African countries need to further engage in Green Climate Fund readiness programmes towards the development of fundable applications. In addition, owing to the level of funding required to address the resilience challenge, mobilizing public and private domestic sources would also accelerate and facilitate resilience development at the country level.

The African continent commands a large renewable energy potential, in the hydroelectric, wind and solar sectors. Increasing the share of renewables in the energy mix will yield high co-benefits in terms of health and employment. To seize the renewable energy opportunity, the report recommends:

- (e) Actively promoting renewable energy through tax and investment incentives (financial and administrative in nature), as well as the inclusion in its cost of negative externalities of fossil fuel use through taxation and the elimination of subsidies (where applicable). Organizing early preparations to hone the skills of the labour force in building and operating renewable energy systems through capacity-building and knowledge transfers will also help local employment to adapt to changing technologies in the energy sector.
- (f) The report supports not only a positive growth in annual investment, but also an increasing amount of investment expenditure relative to GDP in order to increase energy efficiency and reach sufficient levels of production to meet the growing energy demand. Apart from investment incentives, alternative funding opportunities must be explored and scaled-up, including non-conventional financial instruments such as guarantees, green bonds, debt swaps, and the like.

3. Introduction

In recent years, most African economies have experienced strong increases in macroeconomic outputs, improvements in poverty eradication and, more generally, in development (Addison, 2015). With abundant natural resources, such as oil, gas, gold or diamonds, and with an increasingly educated population, Africa is seen as the “rising continent” of the twenty-first century (Lagarde, 2014). Similarly rising are the impacts of climate change on African countries, inducing climate-related disasters. A growing African population is more exposed, and hence, more vulnerable to natural disasters such as droughts and floods. How much of these impacts can be attributed to more intense or more frequent disasters due to climate change is difficult to quantify. The most recent scientific literature, including reports of the Intergovernmental Panel on Climate Change (IPCC), has significantly improved the understanding of climate change and the impacts to which African countries are likely to be exposed in the future. These impacts are projected to have detrimental consequences on economic and human development in developing countries, especially in Africa. In 2013, World Bank President Jim Yong Kim wrote that “a disastrously warming planet threatens to put prosperity out of reach of millions and roll back decades of development” (Schellnhuber et al., 2013).

This report is an in-depth look at how future climate change could affect macroeconomic development and poverty reduction efforts in Africa. It also discusses what can be done to circumvent these negative consequences.

A complex climate-economy-development relationship

The climate, economy and development relationship is intricate, with impacts going beyond agriculture (Dell et al., 2012a) and producing significant higher-order effects on other sectors (Cunado & Ferreira, 2014). Due to their many facets (multi-dimensionality) and large, but varying effects on different income groups (redistributive effects) (Stéphane Hallegatte & Przyluski, 2010), climate-related disasters have significant long-term consequences for human welfare and economic development (Lalthapersad-Pillay & Udjo, 2014). Despite the evidence of lagged impacts of climate-related disasters on output and economic growth, there is a lack of research dedicated to exploring how the effects of disasters transmit through the economy. The difficulty in measuring and quantifying higher-order effects, as well as arriving at a common definition of what constitutes a long-term impact of a climate-related disaster, remains a major challenge in climate disaster studies (Hallegatte & Dumas, 2009).

The African continent has been strongly affected by climate-related disasters in recent decades. In total, African countries incurred damage to a value of US\$14.3 trillion from about 1,335 disasters between 1960 and 2014 (CRED, 2017). Examples of these disasters include the unprecedented and long-lasting Sahel drought from the 1970s onward (Berg, 1976), arguably one the most dramatic droughts in any region of this size observed in the twentieth century; the 1997-8 El Niño-related floods in Kenya, which washed away roads and bridges and resulted in the transport sector incurring up

to 88 per cent of all disaster losses (Benson & Clay, 2004); and droughts in Ethiopia in 1984, 2008, 2011, and 2015, with the last drought putting about 10 million people or a tenth of the population in need of food aid, and about 400,000 children at risk of severe acute malnutrition in 2016.⁹ Climate-related disasters also have the potential to affect all production factors, such as labour supply, capital stock or investments (Hallegatte, 2015).

Future climates of Africa

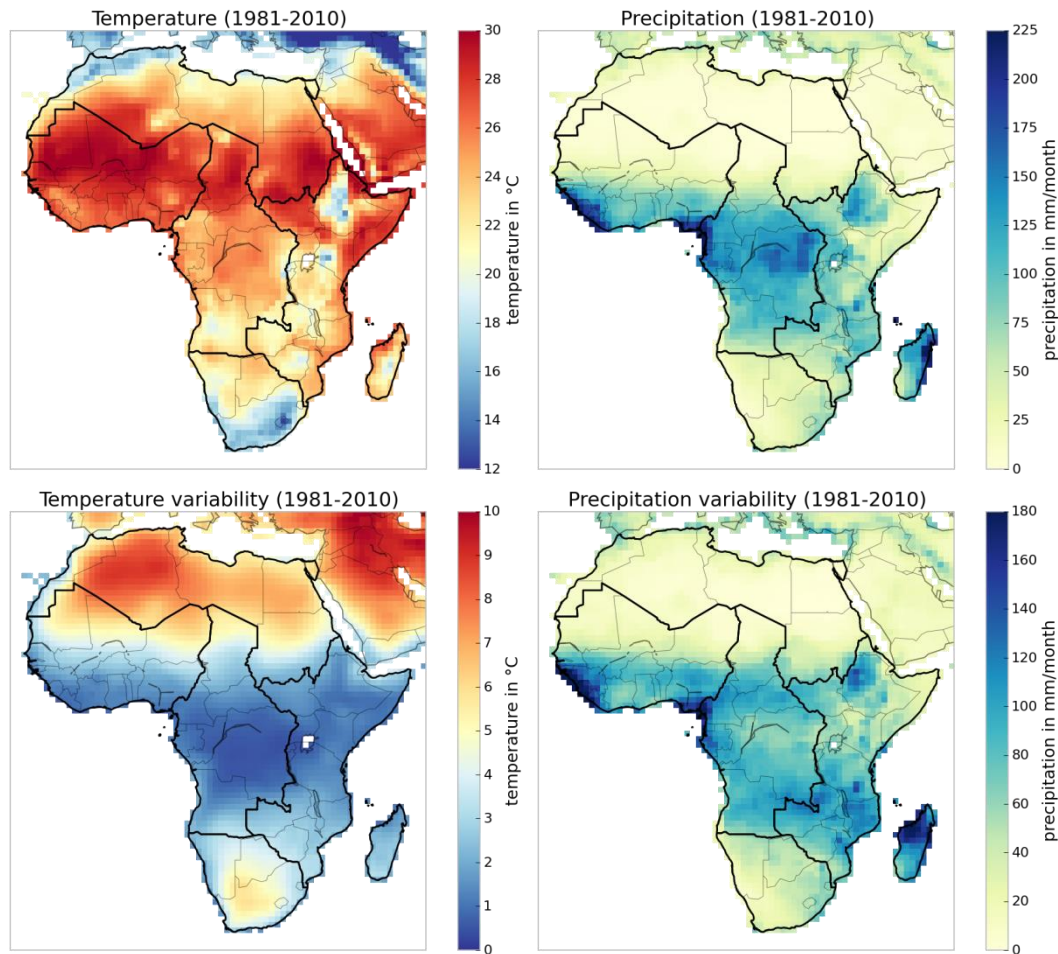
In the next decades, global anthropogenic climate change is projected to continue modifying precipitation and temperature patterns (Figure 4) from what is currently “normal” (**Error! Reference source not found.**). Modifications might increase the frequency and intensity of disasters (Sillmann et al., 2013; Vizzy & Cook, 2012). The climate-change signal has pronounced regional patterns, with precipitation possibly increasing in the Sahel region but decreasing in Southern and Northern Africa. Temperature is projected to increase by about 1°C in Madagascar but by more than 3°C in Northern Africa in 2050 (as compared to 1990) under a high-emissions/warming scenario (RCP8.5). The low-emissions/warming scenario (RCP2.6) displays less dramatic consequences, with less than 2°C warming over most regions.

Africa consists of many diverse climate zones ranging from the hyper-arid climate of the Sahara to the humid tropical climate near the equator (**Error! Reference source not found.**). The African mean climate and its year-to-year variations are shaped by maritime and terrestrial interactions across the continent. For example, the African monsoon system associated with the Intertropical Convergence Zone dominates seasonal rainfall patterns in the northern part of sub-Saharan Africa from June to September and in south-central Africa from January to March.

The devastating droughts that ravaged the Western Sahel during the 1970s and 1980s were linked with abnormally warm oceanic conditions limiting the extent of the West African monsoon to the continental interior (Giannini et al., 2003). Rainfall exhibits notable temporal and spatial variability that can give rise to severe floods and long-lasting droughts.

According to the IPCC Fifth Assessment Report “Africa is one of the most vulnerable continents to climate change and climate variability” (Pachauri et al., 2014). Projected climate change could lead to a spread in aridity, water shortages, ecosystem shifts and changes in the length of the growing season, all potentially having adverse effects on food production and the agricultural sector.

⁹ BBC news article: Ethiopia drought “leaves 10 million without food”, 8 December 2015. Available at <http://www.bbc.com/news/world-africa-35038878>.



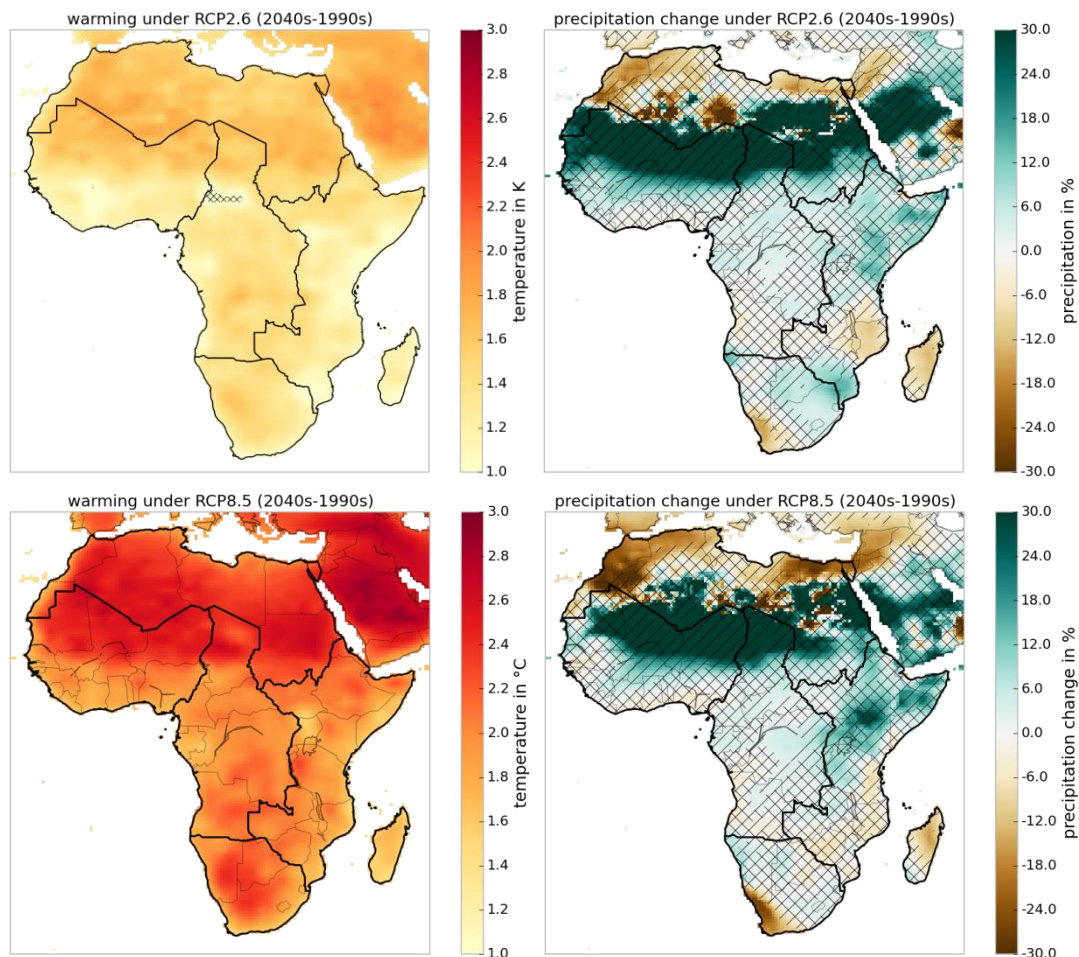
This report uses two climate change scenarios based on anthropogenic climate forcings from the IPCC Fifth Assessment Report (AR5), namely, the RCP2.6 and RCP8.5 scenarios. AR5 climate change projections are made using a hierarchy of climate models ranging from simple climate models, to models of intermediate complexity, to comprehensive climate models, and Earth System Models – the latter with the added capability to explicitly represent the global carbon cycle and biogeochemical processes that interact with the physical climate. AR5 assessed the output of these models based on a set of input scenarios of anthropogenic forcings referred to as the Representative Concentration Pathways (RCPs), within the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) of the World Climate Research Programme. There are four representative concentration pathways: RCP8.5, RCP6.0, RCP4.5 and RCP2.6 – the last is also referred to as RCP3-PD. The term “representative concentration pathways” was chosen to emphasize the rationale behind their use. RCPs emphasize that their primary purpose is to provide time-dependent projections of atmospheric greenhouse gas (GHG) concentrations. In addition, the term “pathway” is meant to emphasize that it is not only a specific long-term concentration or radiative forcing outcome, such as a stabilization level, which is of interest, but also the trajectory that is taken over time to reach that outcome.

Out of the four scenarios assessed in AR5, scenario RCP2.6, which results in about 1.6°C warming by 2050 through to 2100 as compared to pre-industrial levels, shows the strongest levels of global mitigation and reductions in greenhouse-gas emission. In

this report, we refer to the RCP2.6 scenario as “below 2°C world”, or the “low-warming scenario”. On the other side of the emissions spectrum, without mitigation, the RCP8.5 scenario would lead to about 4.5°C warming by 2100 and in this report, we refer to it as “above 4°C world”, or “high-warming scenario”. These two scenarios lead to significantly diverging climates throughout Africa and globally as early as the 2040s (AR5). In the “above 4°C world” scenario, global warming above pre-industrial levels would reach about 2.6°C by 2050, the year that marks the end of the time period of projections of GDP in chapter 2 and development indicators in chapter 3. It should be noted that the choice of these two scenarios is not meant to imply that either is a more likely outcome than other scenarios in the literature (RCPs or others). In climate change research the rationale for working with scenarios is not to predict the future but to better understand uncertainties and alternative futures, in order to consider how robust different decisions or options may come within a wide range of possible futures, and provide a basis for assessing the risk of crossing identifiable thresholds in both physical change and impacts on biological and human systems.

From the multitude of 39 participating models in CMIP5, only five have been selected for this report. These five models are part of a larger impact analysis framework, the Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP), established to provide cross-sectoral global impact assessments (Warszawski et al., 2014). We use the bias-corrected output of these five models, which have been used in the “Turn Down the Heat” reports that assess climate risks, in particular of extreme precipitation and droughts in Africa (Schellnhuber et al., 2013; Schellnhuber et al., 2014; Schellnhuber et al., 2012).

Figure 4 Projected changes in annual average temperature (left) and in annual average precipitation (right) under the RCP2.6 “below 2°C” scenario (upper panels) and the business-as-usual scenario RCP8.5 (lower panels), with the latter exceeding 2°C globally by 2050 and exceeding 4°C by 2100. Shown are the differences between the 2040s (average of 2040 to 2049) and the 1990s (average of 1990 to 1999) of an ensemble consisting of the 5 CMIP5 models used in this report. Crosshatched or hatched regions indicate that the difference between the 2040s and the 1990s period (based on the 5 CMIP5 models) is not significant at the 66 per cent or 90 per cent confidence level.



In a below 2°C world, the warming in the 2040s ranges from about 1°C above the climate “normal” during the 1990s in Middle Africa and the southern coastal part of Western Africa, but approaches 2°C in the Sahel countries, Northern and Southern Africa (see Figure 4 – upper left panel).

For most of the African continent, changes in precipitation by the 2040s in terms of quantity and pattern are not significant according to the projections by the five CMIP models (see Figure 4 – right panel), consistent with findings across all models used in AR5. Southern and Northern African countries would experience a 10 to 15 per cent decrease in precipitation, and 20 per cent in coastal Morocco. Eastern African countries, with the exception of Madagascar and the northern part of Mozambique, would experience a slight wetting in the 2040s as compared to the 1990s (see Figure 4 – upper right panel). However, agreement between global climate models does not necessarily imply high confidence in the projections. The increase in precipitation in the East Africa global models project is not reproduced in regional climate models. On a subregional scale, these higher-resolution models show strongly reduced precipitation, for example

in Uganda and Ethiopia (Schellnhuber et al., 2013). The relative increase in precipitation, between 20 and 30 per cent, across arid and hyper-arid areas, like the Sahara, represents only a very small increase in absolute terms.

In the above 4°C world, Middle Africa warms by about 1.8°C above the climate of the 1990s. In the Sahel countries, Northern and Southern Africa, the projected warming is more pronounced with at least 2.5°C above present-day levels (see Figure 4 – lower left panel). In this scenario, changes in precipitation patterns are more pronounced in particular for drying regions, but still uncertain. Only at the lower 66 per cent confidence interval, arid and hyper-arid areas like the Sahel would see a significant 20–30 per cent increase in precipitation, representing a very small change in absolute terms, given low present-day precipitation. The size of the area and intensity of this wetting signal is reduced under the high-warming scenario as compared to a below 2°C world. At high significance level, Southern and Northern African countries would experience a decrease of more than 20 per cent and as much as 30 per cent along much of the Northern African coastal areas and Western South Africa.

Future climate risk and sustainable development

In recent decades, several African economies have been severely affected by climate-related disasters. For example, the GDP of Senegal decreased by about 19 per cent and that of Burkina Faso by 9 per cent following the 1973 droughts in the Sahel region (Berg, 1976). Even though the capacities of Governments and communities to react to such disasters have improved in recent years, climate-related disasters still affect macro- and microeconomic development. For example, in 2004, a dry spell in South Africa affected 15 million people, making it the second largest disaster in Africa in terms of affected population. The 2012 flood in Nigeria affected seven million people and resulted in direct losses to a value of at least half a billion dollars (CRED, 2017). In the coming decades, countries are likely to be affected at different levels and in different degrees of magnitude as projections of anthropogenic climate change suggest strong variations between regions and diverging from historically observed patterns (Müller et al., 2014; Thornton et al., 2011).

Following the achievements of the twenty-first session of the Conference of the Parties in Paris in December 2015 and the adoption of the Sustainable Development Goals in September of the same year, Africa is now at a climate and development crossroads. Most African countries have the potential to reach higher levels of development, with a chance for some to become middle-income countries in the first half of this century. With rapid economic growth experienced in some countries, such as Ghana with 7.3 per cent¹⁰ in 2013 and Ethiopia with 10.5 per cent in 2013, an increasing number of African countries could progressively reach the emerging countries category before 2050, with a good chance of meeting their SDG targets. Some countries, especially the African Least Developed Countries, will require additional attention and support to meet the SDGs, but all have the potential for strong economic growth in the twenty-first century (African Development Bank, 2011). At the same time, the projected negative impacts of climate change have the potential to alter and slow down this march

¹⁰ Ghana Statistical Service. Accessed on 16 February 2016. Available at http://www.statsghana.gov.gh/docfiles/GDP/GDP2015/Annual_2014_GDP_Rev2_June_2015%20edition.pdf.

towards economic progress and development. An above 4°C world, manifested by temperature increases of up to 3°C and an up to 30 per cent drop in precipitation in Southern and Northern Africa by the 2050s, could have severe human and economic development consequences (Schellnhuber et al., 2013). The choices African policymakers make today will have critical implications for the years and decades to come. They have the opportunity to lay the groundwork for increasing resilience to cope with the future consequences of climate change. They also have the prospect of moving their economies towards low-carbon development and limiting Africa's future contribution to climate change while seizing the benefits associated with early action.

The Paris Agreement secures a long-term multilateral framework and a mode of operation that covers all parties to the Framework Convention on Climate Change. All subjects of key interest for African nations are covered, including mitigation, adaptation, loss and damage, and means of implementation for developing countries. The fact that these are placed firmly under a multilateral agreement is the best hope for addressing these interests comprehensively and in collaboration with Africa's global economic and political allies.

In contrast to the more pessimistic high-warming scenario assessed in this report, the low-warming scenario is consistent with the Paris Agreement, which is the first climate agreement that includes long-term perspectives of temperature increase and emissions limits consistent with holding warming well below 2°C and below 1.5°C, as well as achieving essentially zero global greenhouse gas emissions in the second half of the twenty-first century. These long-term perspectives finally provide a signal to markets, investors and research and development, and must lead to structural investments in mitigation, establishing the required investment mechanisms and infrastructure, building capacity and experience, from which adaptation and loss and damage might also benefit in time.

The long-term temperature and mitigation limits will have implications for the debate on equity. While the appeal for international financial support should remain as strong as ever, emissions should be reduced globally. With strong international financial support, African economies have an opportunity to lead a transformation that will realize climate-resilient sustainable economic growth and development, with an appropriate balance between mitigation and adaptation, and with the Paris Agreement providing a framework for, in its own words, “enhancing adaptive capacity, strengthening resilience and reducing vulnerability to climate change”.

With more and more tangible climate change impacts, moving into the post-Paris world and reaching the SDG targets requires more tailored climate-related information for all policymakers, not only those exclusively concerned with environmental issues. This report investigates the intricate relationship between economic development and climate change in African countries. Chapter 3 quantifies the macroeconomic consequences of climate change. Chapter 4 investigates development risks induced, including its effect on deprivation. Chapter 5 focuses on adaptation needs to support communities coping with the negative consequences of climate change. Chapter 6 investigates economic and development opportunities arising from the implementation of climate change adaptation and mitigation and chapter 7 summarizes key messages and draws recommendations from findings of the report.

4. Macroeconomic and development risks

Researchers associate changes in temperature (Burke et al., 2015; Dell et al., 2012a) and changes in precipitation (Brown et al., 2013) with notable effects on macroeconomic indicators, in particular gross domestic product (GDP), sectoral growth and investments. Using a new econometric model developed for this report, the historical and future effects of climate variability and change on macroeconomic indicators are investigated at the regional and national level. The analysis of the African continent is divided according to geographical regions: Southern Africa (0), Northern Africa (0), Western Africa (0), Eastern Africa (0) and Central Africa (0). The first section provides an overview of the regional estimates and considerations (0).

4.1 Regional estimates and considerations

This chapter estimates the macroeconomic consequences of climate change at the national level in the 2020s, 2030s and 2040s. These consequences were assessed based on the two warming scenarios explained in chapter 1. In the low-warming scenario, the “below 2°C world”, global warming reaches 1.6°C above pre-industrial level by 2050 and is likely to stay below 2°C throughout the twenty-first century. In the high-warming scenario, the “above 4°C world”, global warming reaches 2.6°C above pre-industrial level by 2050 (the end of the study period in this chapter), well on its way to exceeding 4°C by 2100. By aggregating country-level estimates, a clear picture of the negative effects of climate change on GDP emerges, with considerable heterogeneity across Africa (Figure 5).

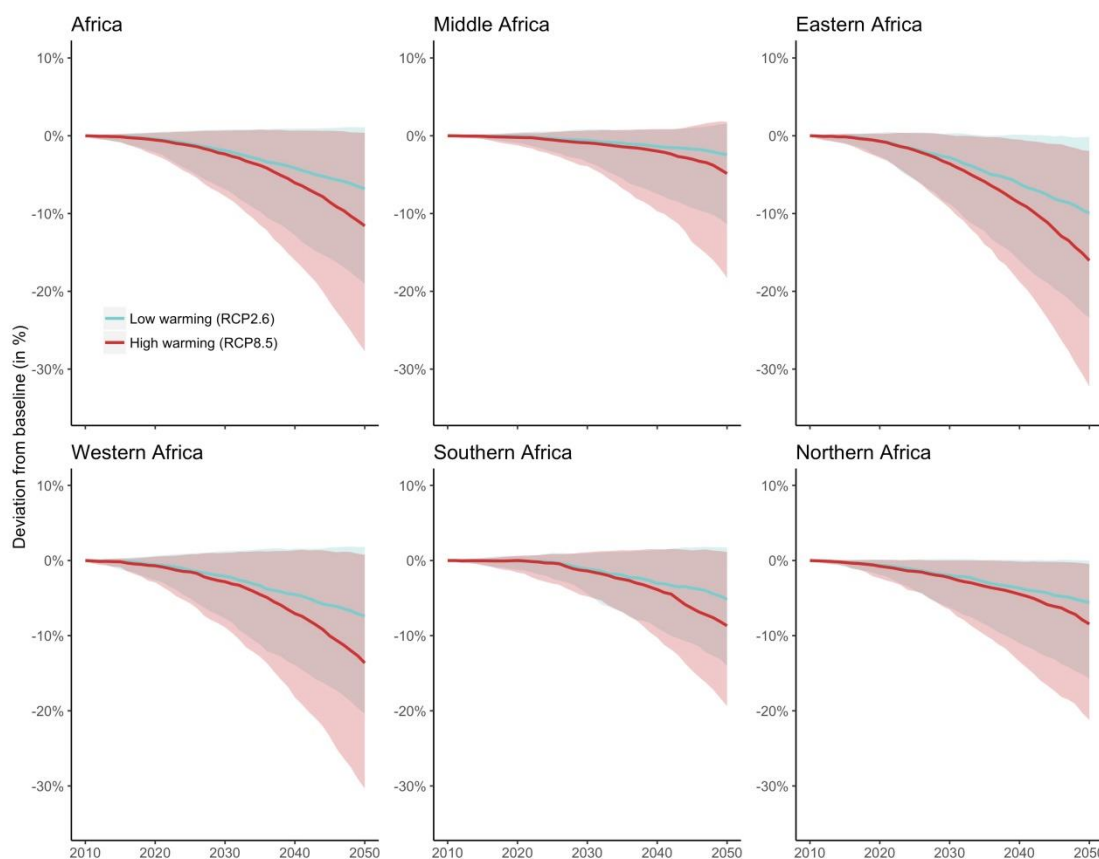


Figure 5 GDP per capita deviation from a GDP per capita baseline scenario (SSP2) resulting from continued global warming for all African countries and the five regions in Africa over the next three decades, in a scenario holding global warming below 2°C (in blue) and a scenario just exceeding 2°C by 2050 (in red) and heading above 4°C by 2100. The ranges represent the 66 per cent statistical confidence interval. Source: authors' calculations based on the econometric-based macroeconomic forecast model described in Box 2 and Annexes.

By 2030, the combined effects of natural variability and climate change could reduce countries' GDP per capita by about 3.5 per cent (-7.0; -0.9) in Eastern Africa, in the high-warming scenario, or have little effect, for example in Central Africa in the low-warming scenario.

By 2040, climate-related events would begin to trigger serious macroeconomic consequences, with Eastern African countries as the most affected, having a reduction of up to 8.6 [-2.9; -14.5]¹¹ per cent in the high-warming scenario as compared to a baseline scenario of GDP per capita. Western African countries would still have consequences limited to -7.1 [-0.7; -14.5] and Northern African countries -4.5 [1.0; -10.2] per cent, as compared to the baseline GDP scenario. In the low-warming scenario, macroeconomic consequences range from -6.2 [-1.9; -12.1] per cent change in Eastern Africa to -1.3 [+0.2; -4.8] per cent in Central Africa as compared to the GDP baseline.

Approaching mid-century, the negative consequences by 2050 continue to accumulate as compared to the GDP per capita baseline scenario. Northern Africa would be significantly drier and warmer, as projected by the climate models used in the study (chapter 1), which is also confirmed by IPCC AR5. In the low-warming scenario, macroeconomic damage would range from -2.4 [+0.15; -7.7] per cent in Central Africa to -10.0 [-3.6; -18.6] per cent in Northern Africa, as compared to the GDP per capita baseline. Finally, during the same period, in the high-warming scenario, strongly negative consequences occur in most African regions; Central Africa is affected the least at -4.9 [-0.6; -12.5] per cent while Eastern Africa faces a critical reduction of -16.0 [-6.7; -26.7] per cent as compared to the GDP per capital baseline.

¹¹ Square brackets indicate a 50 per cent uncertainty interval, with primary drivers of uncertainty the spread in climate-change patterns from the climate models and the determination of parameters for GDP growth in the econometric methodology and modelling.

Box 1 African countries climate-induced historical losses

In recent years and decades, African countries have experienced significant losses from climate-related disasters, like droughts, floods and cyclones. Scientific understanding of these contemporary losses, linked to countries' limited adaptation to their climatic conditions, is still limited. The losses were estimated at about 0.3 per cent of GDP for low-income countries in the period 2001-2006 (IPCC, 2012) and 0.1 per cent for high-income countries. The economic analysis in this report allows for a preliminary investigation of the past effects of precipitation and temperature on African economies. Figure 4.2 below shows estimates of losses in percentage of GDP per capita growth that occurred in the period 1986-2005, as a consequence of the limited adaptation of African countries to fluctuations in their precipitation and temperature patterns from year to year.

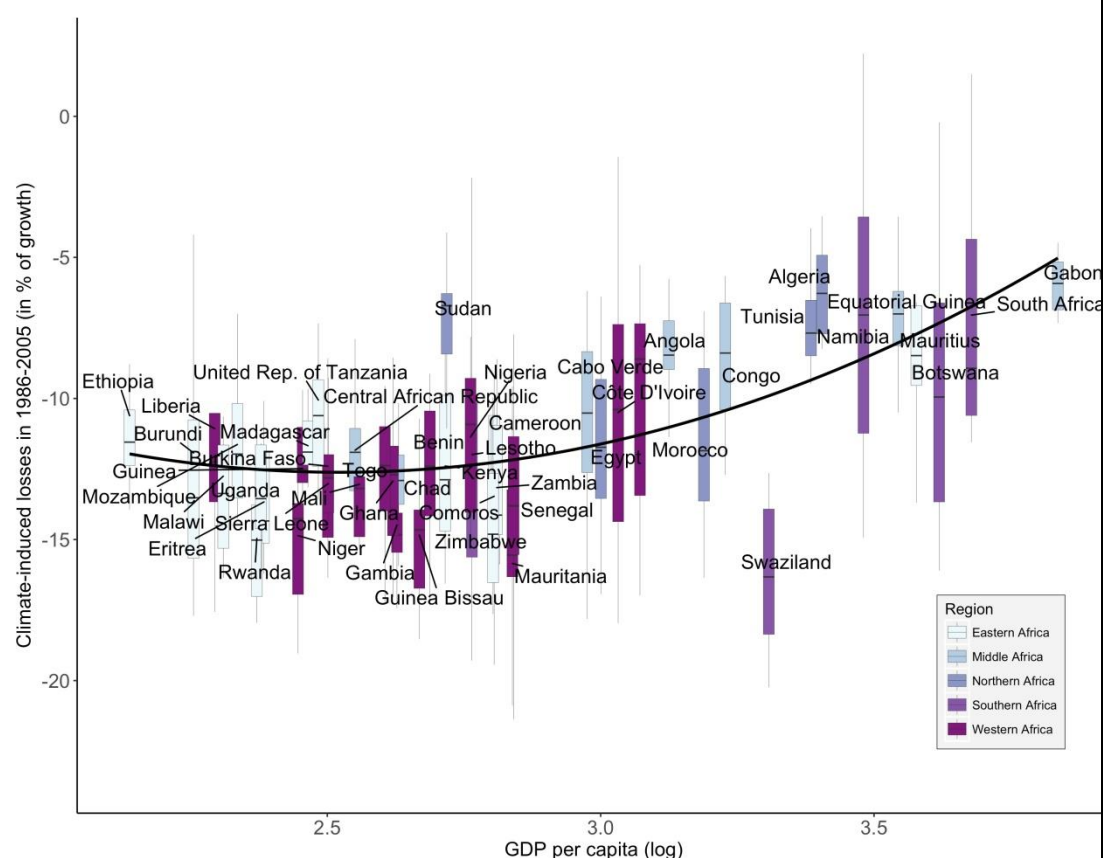


Figure 6 Annual climate-induced (precipitation and temperature combined) losses in the period 1986-2005 measured in percentage of GDP per capita growth. Source: Authors' computation.

As the figure shows, the majority of African countries have average annual losses, induced by climate variability, ranging from -15 to -10 per cent decrease in GDP per capita growth over the 1986–2005 period. Over this 20-year period, the cumulative reduction could range from 5 to 15 per cent (depending on the GDP per capita growth baseline). This suggests that the countries' lack of adaptation to current climatic conditions is already having a cost in economic development and delaying African countries' path to emergence. The range of estimates of 5 to 15 per cent lower GDP per capita as a consequence of this limited adaptation is consistent with earlier studies, which estimated losses at about 8 per cent in GDP over the 1970-2010 period (World Bank and United Nations, 2011) or a decrease by about 15 per cent in GDP per capita – only as a consequence of precipitation – over the period 1960–2000 (Salvador Barrios et al., 2010).

This contemporary occurrence of losses induced by climate-related disasters is defined as an “adaptation deficit” (Bhave et al., 2016; Fankhauser & McDermott, 2014). Its existence and its already measurable impacts economically and socially justify active involvement of African Governments in the conception and implementation of climate-resilient development plans and policies.

In comparison with existing results from top-down integrated assessment models, the estimates of the effects of climate change on macroeconomic output in this chapter seem to be on the high side (compare for example: Schaeffer et al., 2014, using the AD-RICE model, and chapter 4 in this report). Taking stock of most recent scientific literature on the relationship between climate variability / climate change and economic indicators and more generally on climate science, several lines of evidence point in the direction of higher climate change risks and therefore damages:

- The top-down models mentioned above are limited to available literature assessments of particular mechanisms that relate climate variability and change to effects in particular sectors. These models therefore do not capture the whole economy and cross-sectoral effects (see chapter 4).
- This chapter’s estimates of the effects on GDP per capita result from the aggregate consequences of climate-related temperature and precipitation events on GDP per capita growth, in comparison to GDP per capita growth in the baseline scenario. The reduction of 16 per cent of GDP by the 2040s from the baseline (this chapter’s highest risk estimates) translates into annual GDP per capita growth less than half a percentage point lower than the baseline growth every year between 2015 and 2050. By comparison, focusing only on African countries, Abidoye & Odusola, (2015) found that an increase of 1°C in temperature could reduce GDP growth by a 0.67 percentage point. Investigating the effects of temperature rise on sub-Saharan countries, Dell et al. (2012a) found that every degree increase could lead to a decrease of 1.9 percentage points in GDP growth. By the 2040s most African countries would be exposed to at least 1.5°C increase as compared to present-day levels. Analysing the consequences of precipitation changes on GDP per capita, Brown et al. (2013) found that if a country’s territory exposed to drought (defined using a precipitation index similar to one used in this chapter) grew by one per cent, GDP growth in the same year could decrease by 2.7 per cent.
- The econometric-based approach used for forecasting future effects of climate variability and climate change on macroeconomic indicators is guided by the concept of “climate analogues” (Stephane Hallegatte et al., 2007). In this respect, this approach may be conservative in forecasting future effects of climate change, as some future climate-related events may be unprecedented during the recent decades and their effects cannot therefore be modelled reliably, or not at all. These include continued sea-level rise, tropical cyclones occurring in higher latitudes, unprecedented heat extremes, etc. (Schellnhuber et al., 2013). In this study’s forecasts, climate-related macroeconomic risks have two climate drivers: a linear effect of temperature on GDP and a stochastic non-linear effect of precipitation – both relying on state-of-the-art Global Climate Model (GCM) outputs. As a consequence, when one of these models projects that a country could be exposed to a geographically extensive and long drought or an exceptionally mild and wet year, the forecast methods account for strong negative effects or positive effects on GDP

growth, affecting GDP levels in subsequent years. This use of GCM outputs forms the stochastic component of the macroeconomic forecast.

- More recent publications (Burke et al., 2015; Du et al., 2017) tend to indicate that earlier assessments of the effects of climate change on economic development were underestimates, as also pointed out in Stern, (2013). For sub-Saharan countries, Burke et al. (2015) estimated a potential mean reduction in GDP per capita of about 25 per cent in 2050, ranging up to 50 per cent in the high-warming scenario – almost twice as much as the estimated effects in this report, with this report taking into account conditions across Africa more specifically than was done by Burke et al (2015).

At this stage, these estimates assume no change in the macroeconomic and governance structures of the African countries. An enhanced approach, with access to adequate sectoral data, would allow for the development of macroeconomic structure scenarios of, for example, the decrease, increase or stagnation of the share of the agricultural sector in economies over the coming decades.

4.2 Southern Africa

The Southern African region includes Botswana, Lesotho, Namibia, Swaziland and South Africa. The region has experienced rapid economic development during the last decades, with South Africa strongly driving the growth in the region. For example, South Africa's services sector provides financial and banking services to the whole region and many other African countries beyond Southern Africa. Despite this significant economic development, the countries of the region are still vulnerable to the consequences of climate-related disasters. According to news reports at the end of 2015, about 2.7 million South African households were affected by one of the worst droughts since the 1980s.¹² This drought is likely to have a negative effect on crop yields and livestock, resulting in reduced overall production and macroeconomic output. According to projections, Southern Africa will experience more frequent and more intense droughts in the coming decades.

The following section provides an analysis of how future extreme dry events, as well as heavy rainfall and increases in temperature, can affect economic production and macroeconomic output. Such macroeconomic indicators do not capture all effects on the population, including, for example, subsistence farmers, that leave little mark on national and regional economic growth numbers. For that reason, we also explore the climate-change impacts on a multi-dimensional indicator for poverty in the next chapter (chapter 3).

4.2.1 Current and future socioeconomic and climatic situation

Southern Africa's gross regional product was US\$326 billion in 2010 (constant 2005 US\$). South Africa accounted for the largest share of it, with a GDP of about US\$300 billion (World Bank, 2017). The services sector constitutes 67 per cent of regional

¹² Al-Jazeera, 4 November 2015. Available at <http://www.aljazeera.com/news/2015/11/south-africa-midst-epic-drought-151104070934236.html>.

product, followed by the industry sector at 31 per cent and agriculture accounting for a minimal share of only 3 per cent. In contrast to other African regions, Southern Africa and Northern Africa both have the largest share of the industry and services sectors in percentage of gross regional product. Namibia, Lesotho and Swaziland display a higher share of agriculture in their GDP, between 7 and 9 per cent (World Bank, 2017). Despite this, and despite South Africa accounting for the largest share of the Southern Africa economy, the structure of the economies in the region is rather homogeneous. All Southern African countries have very low external debt level as compared to their GDP (World Bank, 2017).

In the baseline scenario where climate change does not affect macroeconomic development, the region would grow on average by 3 per cent per annum between 2010 and 2050 (in a “middle-of-the-road” scenario: see Dellink, Chateau, Lanzi, and Magné, 2015). However, Lesotho, Namibia and Swaziland are projected to experience annual growth above 3.5 per cent and up to 4.9 per cent over the same period. By 2050, in this non-climate change scenario, gross regional product would be about US\$1.9 trillion (PPP), with South Africa accounting for 90 per cent of the regional product, only a slightly smaller share as compared to now.

In both low- and high-warming scenarios, the climate of Southern Africa would become increasingly drier during the period 2015-2050, as compared to the present day. Even though global climate models show different degrees of precipitation reduction, there is a clear signal of reduced precipitation emerging from the models analysed in the study in all seasons across western Southern Africa (up to 30 per cent below present-day precipitation), and warming in sub-Saharan Africa stronger than elsewhere, both leading to drying as confirmed by IPCC AR5. As mentioned in chapter 1, the magnitude of changes in precipitation and temperature is considerably smaller in the low-warming scenario.

4.2.2 Macroeconomic risks

During the past decades, climate-related disasters such as droughts and extreme wet events have affected microeconomic and macroeconomic indicators (CRED, 2017). This section contains estimates of future macroeconomic and development effects of these climate-related disasters, projected to increase in intensity and frequency, and the effects of the progressive shift towards a drier climate as a result of climate change. Future impacts of climate change on macroeconomic indicators for Southern Africa and all other African regions are projected using an econometric-based macroeconomic forecast model, described in Box 2.

Box 2 Econometric-based macroeconomic forecast model

The econometric-based macroeconomic forecast model developed for this report uses past and projected grid-level climate data as variables influencing economic indicators.

Guiding principle

The guiding principle underlying the model is that precipitation events and temperature levels of the same intensity will have the same macroeconomic effects expressed in percentage points of GDP in the near future as they had in the recent past. This econometrically-inferred macroeconomic effect in relation to a given intensity of precipitation is termed *sensitivity* in this report and builds on the theory of *climate analogues* (Hallegatte et al., 2007).

Econometric approach

Sensitivities are inferred using a piecewise multivariate regression model, which uses GDP per capita (in log) as dependant variables, and segments of precipitation intensity as well as temperature variation against a historical mean or a historical trend as independent variables. The model also includes control variables such as oil prices, government spending, external debt, etc. Precipitation intensity is defined using an index, which normalizes precipitation and allows for comparison from one country to another even though precipitation levels are of a different magnitude. The model employs the Standardized Precipitation Index SPI (Vicente-Serrano & López-Moreno, 2005). Exposure to bins of precipitation intensity is calculated by measuring the percentage of area of a country, during a given year, exposed to a segment within the broader range of the index on a monthly basis.

Climate-induced GDP adjustment

The projections for the coming decades are realized using the sensitivity coefficients inferred by the regression model and exposure to the same range of precipitation intensity and temperature deviation using the grid-level bias-corrected projections of five Global Circulation Models from the Coupled Model Intercomparison Project Phase 5 (CMIP5) (Hempel et al., 2013). The level of future GDP per capita growth exposed to climate risks or “GDP per capita growth at risk” is computed in two scenarios, the RCP8.5 scenario (called *above 4°C world* in this report) and the RCP2.6 scenario (called *below 2°C world* in this report).

The impact on countries’ GDP is projected by integrating the risk to GDP per capita growth in both scenarios (RCP2.6 and RCP8.5) in the GDP per capita growth projections from the SSP2 scenario (so-called “middle-of-the-road” scenario: see Dellink, Chateau, Lanzi, & Magné, 2015) between 2015 and 2050.

Analysis of the model results

For every year, country, model (five GCMs from the CMIP5 database) and scenario (RCP8.5 and RCP2.6), the economic model produces 10 macroeconomic effects estimates for the period 2015-2050 (therefore 50 for every year, country and scenario).

Sensitivity of Southern African economies to climate stressors

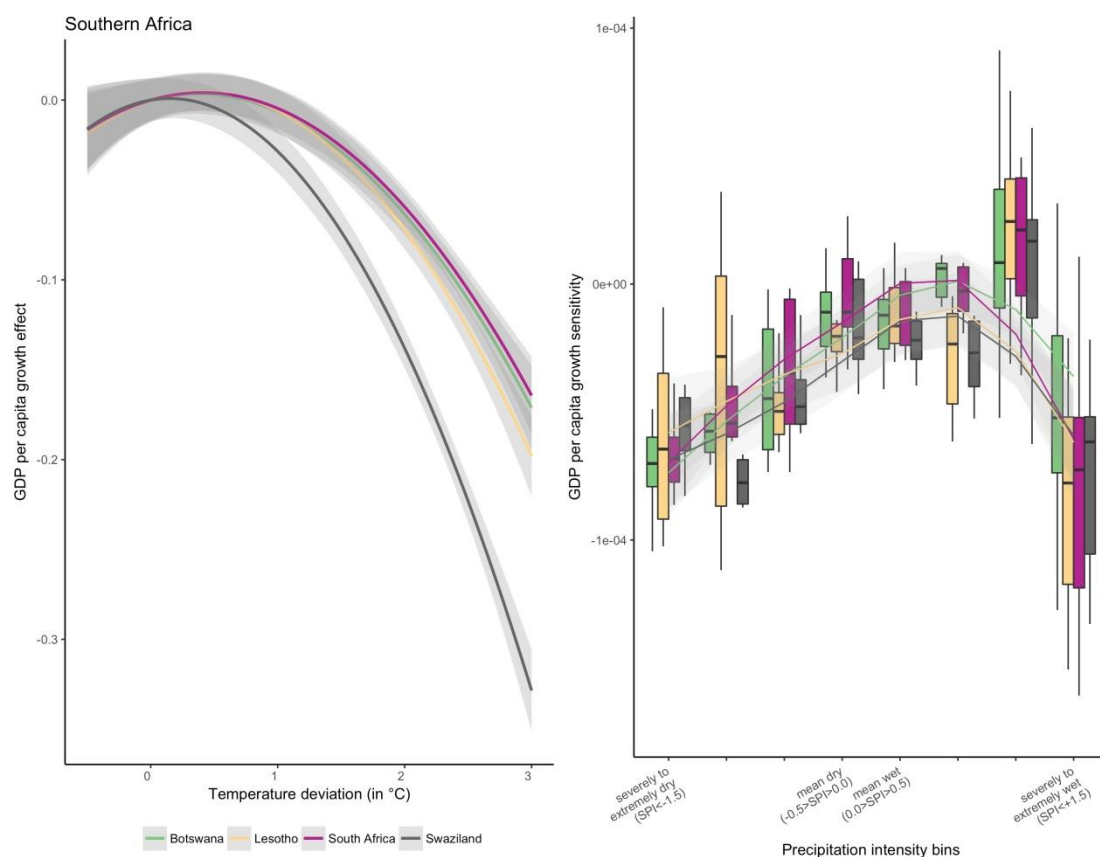
The developed model has the ability to detect the specific sensitivity of the regional economies to different types of precipitation events, ranging from extreme dry events to extreme high precipitation. Depending on the sectoral structure of the economy, the sensitivity to climate-related events can fluctuate – for example, a country with a large agricultural value added share would be more affected by dry spells, while a more industrial or services sector-dominated economy may be more affected by extreme wet events, for example due to business disruptions caused by flooding.

Southern African economies display a similar macroeconomic structure, with the agricultural sector playing a limited role, from 3 per cent in South Africa to a maximum of 9 per cent in Namibia, with 3 per cent regional average in 2010. The region’s economies were affected by both extreme dry and wet events between 1980 and 2014.

According to the econometric analysis of the past decades, the effect of extreme wet events on GDP is twice as large as that of extreme dry events, for a comparable spatial extent.

Figure 7 displays the sensitivity to precipitation of Southern African economies to extreme dry (left) and extreme wet events (right) and its mean precipitation climate (mean dry and mean wet in the middle).

Figure 7 Temperature effect (left panel) and precipitation sensitivity of Southern African economies for the period 1980-2014. The temperature deviation is measured against the mean temperature in the 1951-1980 period. Source: authors' calculations based on the econometric-based macroeconomic forecast model described in Box 2.



In addition to being sensitive to precipitation variability and extremes, Southern African countries are also affected by changes in temperature. Temperature rise has been recurrently analysed as a potential driver of negative impacts on macroeconomic outputs (Burke et al., 2015; Dell et al., 2012a), through, for example, decreases in labour productivity induced by heat extremes (see for example Heal & Park, 2013, for the USA) or the negative consequences on crop yields (Schlenker & Roberts, 2009, also for the USA). In Southern African countries, the range of temperature under which economies produce at their best spans from 0 to 1°C, with Swaziland being almost twice as much more sensitive to temperature increase than Botswana, Lesotho and South Africa.

Future effects on GDP

In Southern Africa, climate change would result in lower precipitation and higher temperature in both high- and low-warming scenarios, based on the observed sensitivity between precipitation extreme, mean precipitation, climate and temperature during the period 1980-2014. GDP per capita, future risk for GDP per capita growth and its subsequent consequences on GDP per capita are estimated and then compared to a non-climate change economic growth scenario. Effects on GDP per capita growth and GDP per capita are estimated for the period 2015-2050.

In a below 2°C world the macroeconomic consequences of climate change are restricted to 5.2 [-11.7; 0.1] to 8.7 [-15.7; -1.1] per cent decrease by 2050 as compared to GDP per capita in a non-climate change scenario. In 2030 and 2040, the aggregated macroeconomic effect remains limited, with countries facing a macroeconomic output per capita decrease of 1 to 4 per cent below output in a non-climate change scenario.

As a consequence of stronger drying and warming trends in the region in the above 4°C world, macroeconomic consequences are more pronounced. By 2030, projected consequences for GDP per capita are limited to a -0.6 per cent (in South Africa) to -1.9 per cent (in Botswana) deviation. By mid-century, the effect becomes severe with a reduction in GDP ranging from 2.6 [-9.0; 1.2] per cent in South Africa and Botswana to above 8 [-14.0; -3.8] per cent in Swaziland. The following figure (Figure 8) displays results for the 2020s, 2030s and 2040s in a below 2°C world (blue) and above 4°C world (red).

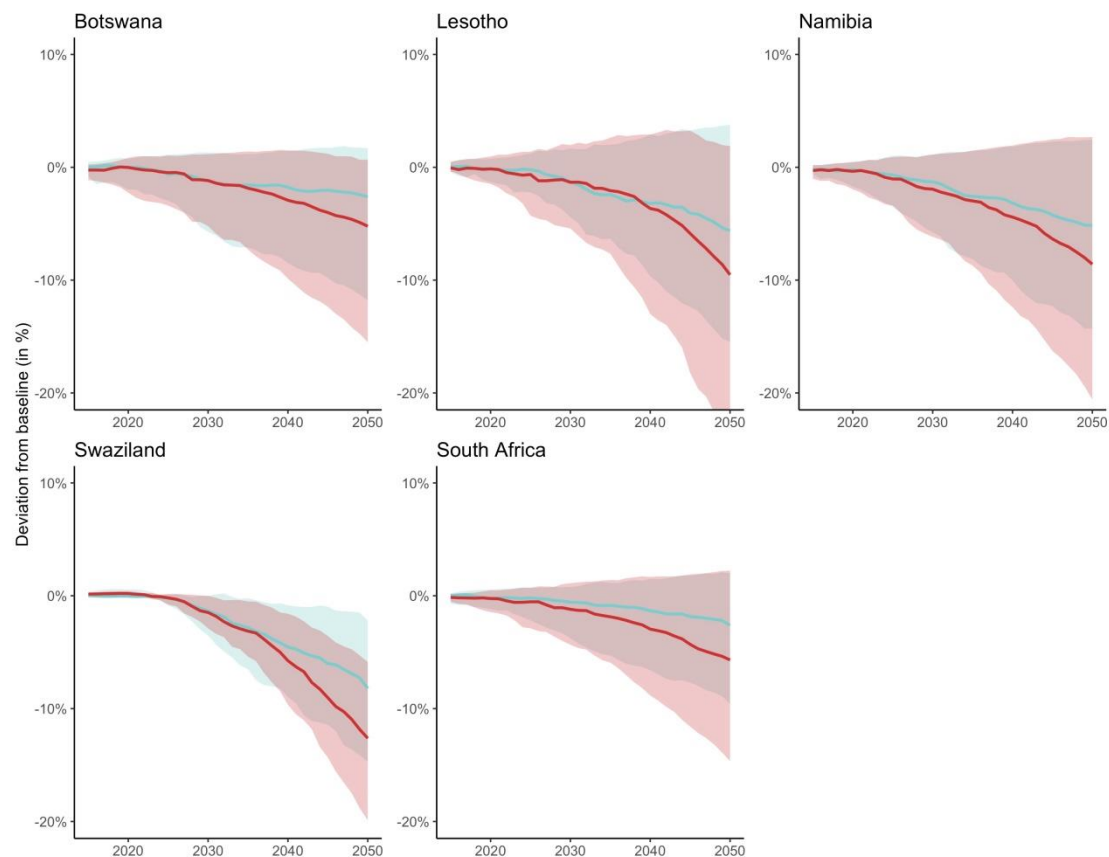


Figure 8 GDP per capita change in a below 2°C (blue) world and above 4°C (red) world as compared to a non-climate change scenario (SSP2) for Southern African countries for the 2015-

2050 period. The range represents the 66 per cent statistical confidence interval, while the line shows the medians of all risk estimates. Authors' calculations are based on the econometric-based macroeconomic forecast model described in Box 2.

In the above 4°C world, GDP per capita values would be significantly lower than in the baseline scenario. This notable effect on GDP is a translation of the rising and aggregate effect on annual economic growth of the warming and drying trend affecting Southern Africa. Furthermore, the aggregation of the effect of climate-related disasters on GDP growth and then on GDP accounts for the detrimental macroeconomic consequences of large-scale dry and wet extreme events, which adversely affect GDP growth – replicating extreme events experienced by these countries in the reference period (1980–2014).

Until 2030, the countries of the region would be similarly affected in both high- and low-warming scenarios but the two scenarios begin to diverge after the 2030s. By the 2040s, the negative consequences on GDP per capita in the high-warming scenario are already at least 15 per cent higher than in the low-warming world. This deviation further exacerbates with time. In 2050, the losses in the high-warming scenario are double the losses in the low-warming scenario in Botswana and South Africa, highlighting the importance of global mitigation actions and its benefits at the country level.

4.2.3 Regional conclusions and implications

Projections show that Southern African countries will be significantly affected by climate change in the next decades in the absence of adequate adaptation measures. The macroeconomic impacts are mostly fuelled by the drying and warming trend in both low- and high-warming scenarios. Two concrete implications arise from the analysis of Southern Africa's climate-induced macroeconomic risks:

1. Owing to the magnitude of the projected macroeconomic consequences in both warming scenarios, and especially in the above 4°C scenario, mitigation and adaptation cannot be neglected as solely “environmental” questions. By the 2050s, median GDP per capita risk could be up to 3.5 percentage points higher under a high-warming scenario as compared to a low-warming scenario. The effects of climate change on macroeconomic development and poverty eradication should be better integrated in development planning at all administrative and governance levels.
2. Measures in all sectors to adapt to changes in water availability, decreases in precipitation and rising temperatures could be rapidly scaled up, as some already significant macroeconomic consequences would be felt as early as the 2030s. However, adaptation strategies to extreme dry events also need to account for current macroeconomic sensitivity to extreme wet events – potentially making the choice of adaptation options and measures more intricate.

4.3 Northern Africa

Enclosed by the Atlantic Ocean to the west, the Mediterranean Sea to the north, and the Red Sea to the east, Northern Africa includes Algeria, Egypt Libya, Morocco, the Sudan

and Tunisia. Algeria, Egypt and the Sudan are oil and gas producers. The production and exportation of natural resources help to create a buffer against external stressors to the domestic economy, such as climate-related disasters, and therefore limit their negative consequences (Abidoye & Odusola, 2015). The countries of the region display a rather similar geographical profile with long coastal zones and large parts of territory extending into the Sahara desert. Areas that are not part of the Sahara are projected to warm rapidly and be confronted with declining precipitation (chapter 1). The bulk of the economic activity of these countries takes place on a very narrow band of territory along the coastlines. This increases Northern Africa's vulnerability to climate-related impacts at the macroeconomic level, as risk is not spatially diversified across the territory. This specific feature of these countries will be a significant driver of macroeconomic consequences of future climate change impacts on Northern African economies.

4.3.1 Current and future socioeconomic and climatic situation

Northern Africa has the continent's highest gross regional product – about US\$450 billion (constant 2005 dollars), with the industry and services sectors accounting for 94 per cent of the regional product. This regional average hides some large contrasts across countries, for example the Sudan's agricultural sector represents 25 per cent of its value added. Egypt and Morocco also generate a significant portion of their GDP from agriculture – 14 per cent and 15 per cent respectively. Earlier studies (Dell et al., 2012a) have shown that these important shares of agricultural production in countries' output tend to increase their macroeconomic vulnerability to extreme dry events and heat extremes.

In a baseline scenario in which climate change would not affect future macroeconomic development, the gross regional product would increase to US\$5.9 trillion (PPP). According to this scenario (same reference as for all other regions), economies would grow per annum between 2.9 per cent (Algeria) and 5.4 per cent (Sudan) from 2010 to 2050.

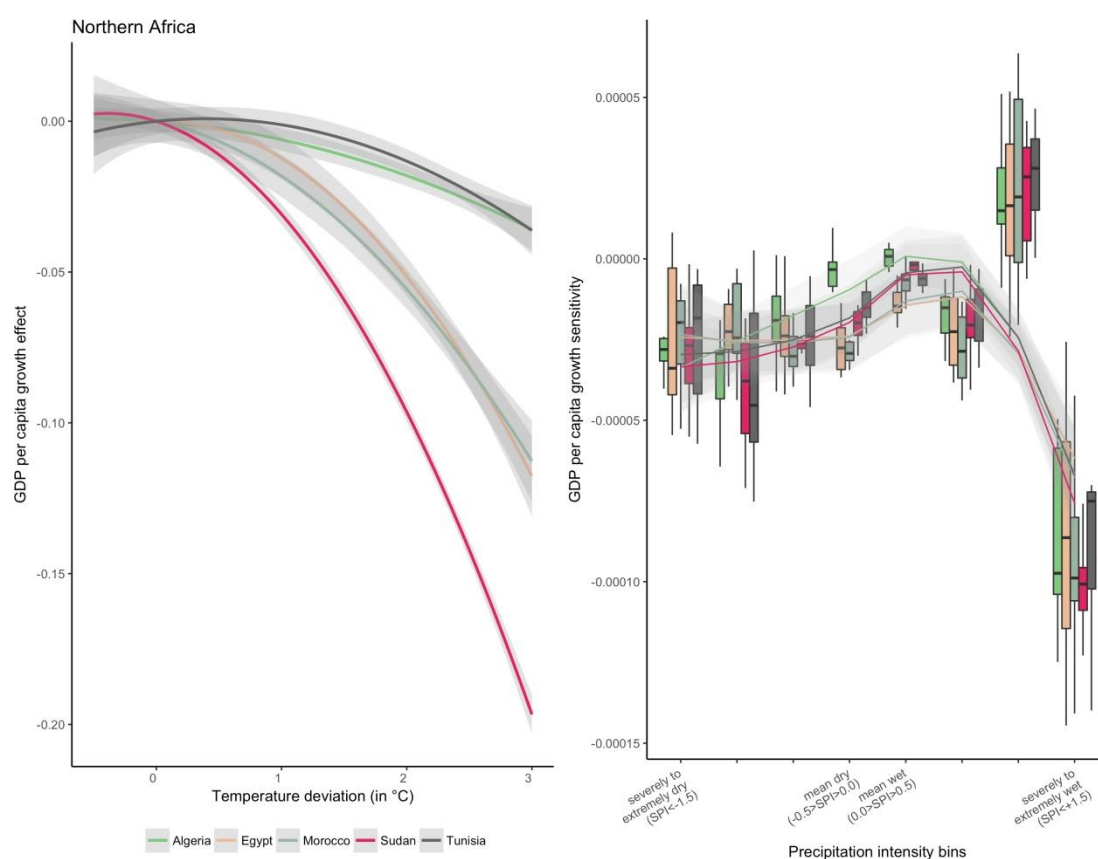
In both warming scenarios, Northern African countries would be exposed to very similar climate change-induced changes in precipitation and temperature during the 2015-2050 period. The northern part of Northern Africa would become significantly drier with a precipitation decrease ranging from 6 to 12 per cent in the low-warming scenario, and more than 18 per cent in the high-warming scenario. In both scenarios, the southern regions of these countries would become wetter with a significant relative increase in precipitation, but very little increase in absolute terms. The Red Sea coastlines of Egypt and the Sudan could experience relatively wetter conditions in both scenarios. It is worth noting that, first, the wetting trend projected for the southern regions of these countries represents a relative increase compared to present-day extremely low precipitation (desert areas) and, second, a (very small) increase in precipitation is not likely to render significant economically beneficial effects owing to the absence of economic activities in these areas.

4.3.2 Macroeconomic risks

Sensitivity of the economy to climate stressors

Even though the share of the agricultural sector has been decreasing in the last decades, Northern African economies and employment still depend on the agricultural sector. As of 2010, agriculture still accounted for 6 per cent of total regional production, but employment in this sector was relatively high, ranging from roughly 10 per cent in Algeria, to 30 per cent in Egypt and 40 per cent in Morocco in 2011 (World Bank, 2017). The large share of the agricultural sector in the regional economy and employment is a possible explanation for the strong negative sensitivity of GDP to extreme dry events.

Figure 9 Temperature effect (left panel) and precipitation sensitivity of Northern African economies for the period 1980-2014. Source: authors' calculations based on the econometric-based macroeconomic forecast model described in Box 2.



On the other side of the precipitation spectrum, extreme wet events are also associated with a negative effect on macroeconomic output. However, this effect is particularly large¹³ as compared to the macroeconomic consequences of droughts.

Temperature change also affects macroeconomic outputs in the region. As in the Southern African countries, the optimal temperature ranges from 0°C to 1°C. However, the pattern of temperature vulnerability is very different across the five countries. The Sudan is the most sensitive, followed by Egypt and Morocco at a rather similar level

¹³ The macroeconomic effects of very wet events – or floods – need to be interpreted with care in this report. The Standardized Precipitation Index (SPI) used for this analysis does not properly capture flooding risk and intensity for at least two reasons: (1) As a precipitation index, it does not account for the characteristics of the hydrological basins of the countries; (2) The SPI is calculated on a monthly basis, while extreme precipitation events leading to flooding events usually occur over a shorter period of time.

and then Tunisia and Algeria. The share of the agricultural sector follows approximately the same ranking. Furthermore, even though the economic model accounts for the effects of natural resources on macroeconomic outputs, it appears in the analysis that oil- and gas- (in general mineral resources) rich countries tend to be significantly less sensitive to changes in precipitation and temperature than the other countries.

Future effects on GDP

In both warming scenarios, climate change will lead to higher precipitation decrease and temperature rise across economically active and populated areas in this region as compared to the other African regions. Northern Africa's coastal zones are particularly at risk of an increasing trend in droughts (Giannakopoulos et al., 2009; Hoerling et al., 2012; Schellnhuber et al., 2014) due to this combination of rapidly increasing temperature and decreasing precipitation. In combination with the relatively high sensitivity to extreme dry events, this projected increase in dryness over Northern Africa's coastal areas could have detrimental consequences in both low- and high-warming scenarios.

In the 2020s, the small climate-change signal in both climate scenarios in projected temperatures would affect macroeconomic product by between 0 and -5 per cent as compared to the baseline scenario. By the 2030s, all the countries in the region would begin experiencing negative effects of the early onset of a strong climate change signal. On average, this GDP decline across all countries is projected between 5 and 15 per cent as compared to the baseline scenario.

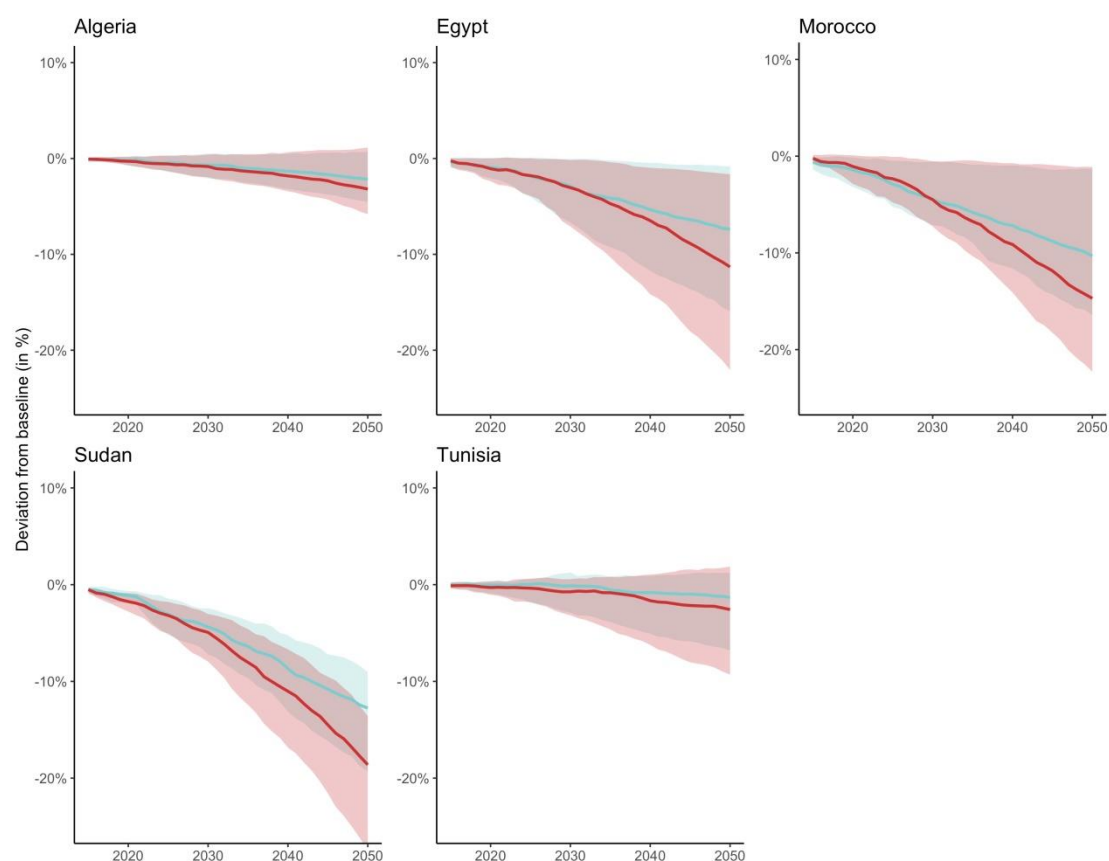


Figure 10 GDP per capita change in a below 2°C (blue) world and above 4°C (red) world as compared to a non-climate change scenario (SSP2) for Northern African countries for the 2015-2050 period. The range represents the 66 per cent statistical confidence interval, while the line shows the medians of all risk estimates. Authors' calculations are based on the econometric-based macroeconomic forecast model described in Box 2.

In contrast to findings for Southern Africa, an emerging divergence in the median risks between low- and high-warming scenarios by the 2040s is not as clearly observed yet for Tunisia and Algeria. In both scenarios by this time, the effects of climate change could limit GDP per capita to 1.3 [-5.2; 0.9] to 18.6 [-14.3; -25.0] per cent below the baseline scenario, respectively for Tunisia in the low-warming scenario and the Sudan in the high-warming scenario. The risk for these countries fluctuates from -2.2 to -3.2 per cent for Algeria in the low- and high-warming scenario and from -10.3 to -14.7 per cent for Morocco, in low- and high-warming scenarios, as compared to the GDP baseline scenario. The uncertainty originates from at least two sources: (1) the climate models used, which show differences in precipitation and temperature changes for these countries, and (2) the uncertainty surrounding the set of sensitivity coefficients selected.

4.3.3 Macroeconomic risks under structural change

Structural change – the adaptation silver bullet?

Structural change towards industrialization and services is a fundamental driver of development, by changing labour flows from low-productivity and resource-intensive activities to high-productivity ones (McMillan & Rodrik, 2013; Rodrik, 2013). By reducing the share of agriculture in GDP, structural change could also lead to a decrease in macroeconomic sensitivity to climate-related disasters, as agriculture is one of the most sensitive sectors, exerting a disproportionate influence on economic susceptibility (Mendelsohn et al., 2001). Therefore, structural change in dynamic economies is often perceived as an approach to limit the future negative macroeconomic consequences of climate change (Kocornik-Mina & Fankhauser, 2015). The following section provides a preliminary assessment of the effects on climate change-related macroeconomic risks induced by structural change, involving a reduction of the share of the agricultural sector as compared to the services and industry sectors.

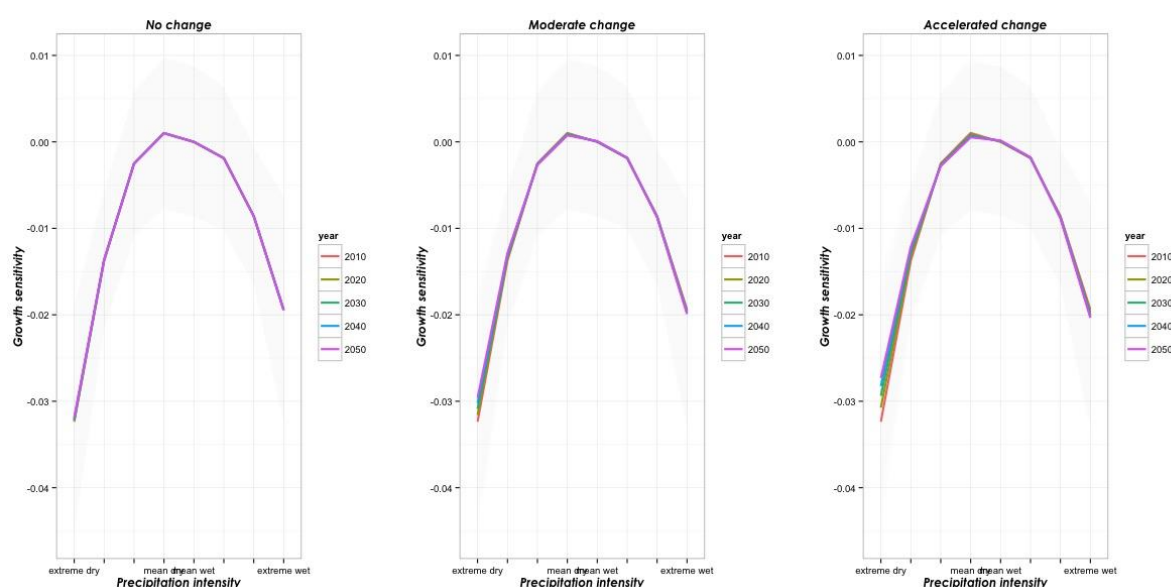
Changing sensitivities

To encompass a large range of possible structural changes that could occur in the coming decades in Northern Africa, two structural change scenarios are assessed as variants to a baseline scenario. In the baseline scenario, there is no structural change, assuming that the macroeconomic structure of the 1980-2012 period remains constant. In the second scenario, agricultural value added decreases from about 12 per cent of regional GDP in 2012 to 9 per cent in 2050. This change is similar to the change observed in the 1980-2012 period across the region. This scenario is called “*moderate change*”. Finally, a third scenario, in which agricultural value added decreases from about 12 per cent to 6 per cent in 2050, halving current agricultural share, is called “*accelerated change*”. The interaction between two sectors is modelled: agricultural sector and the “rest of the economy”, which includes services and industry. In this approach, the sectoral sensitivity is assumed constant over the period 2015-2050, so that the change in macroeconomic sensitivity is purely a result of shifting relative shares

of sensitivities between the agricultural sector and the “rest of the economy” as a result of structural change.

The climate-growth sensitivity is computed for the period 2015-2050 in these three scenarios. As shown in the following figure (Figure 11), the sensitivity to extreme and severe wet and dry events fluctuates within the period for the moderate and accelerated structural change scenarios.

Figure 11 – Northern African region sensitivity to precipitation extremes in three structural change scenarios: no change (left panel), moderate change (middle panel) and accelerated change (right panel)



Overall, the cumulative sensitivity of growth is 2.6 per cent lower in the moderate structural change scenario and sensitivity is 5.1 per cent lower in the accelerated change scenario, both as compared to the scenario without structural change. This indicates that structural change reduces macroeconomic sensitivity to precipitation variations. However, the effect induced by structural changes on sensitivity to extreme precipitation events is not symmetric. Sensitivity indeed decreases for extreme dry events but increases for extreme wet events. In 2050, the sensitivity of growth to extreme and severe dry events (extreme dry in Figure 11) would decrease by 8.6 per cent and 17.1 per cent in the moderate and accelerated change scenarios, respectively. This steep decrease in sensitivity to extreme and severe dry events is explained by the particularly strong sensitivity of the agricultural sector to droughts (Mendelsohn et al., 2001). On the other hand, while agricultural value added growth benefits from very wet events, the services and industry sectors (i.e. rest of the economy) have historically experienced negative consequences from extreme and severe wet events, possibly triggered by business disruptions, including supply chain interruption, unavailability of essential infrastructure (roads, harbours, etc.), destruction of productive assets (Stephane Hallegatte, 2015; Shabnam, 2014; Zylberberg, 2012), etc. As a consequence of structural change, the macroeconomic sensitivity to extreme and severe wet events is projected to slightly increase by the end of the 2040s at 2.2 per cent in the moderate structural change scenario and at 4.4 per cent in the accelerated change scenario, as

compared to the scenario without structural change. The asymmetric effect of structural changes to dry and wet extremes has implications for the prioritization of adaptation interventions: if a strong shift from agriculture to other sectors is expected in a particular economy over the next few decades, the importance of implementing flood-protection measures would be larger as compared to the past.

Improving and worsening macroeconomic risks

Following a shift from agriculture to other sectors, overall macroeconomic sensitivity is projected to decrease, with a particularly steep decrease for extreme and severe dry events, somewhat offset by an increased sensitivity to extreme and severe wet events. The effects of climate change on precipitation patterns in Africa are not projected to be uniform across countries and regions (see Introduction). Some countries and regions are projected to experience a drying trend (parts of Northern Africa), while other regions could observe a wetting trend accompanied by an increase in extreme wet events (Sahel countries, for example). Owing to these differences in the precipitation trend, it is investigated here whether a change in overall macroeconomic sensitivities induced by structural change would only have beneficial effects on future macroeconomic risks in the Northern African countries. Indeed, depending on whether or not the countries are projected to be increasingly exposed to extreme and severe wet events, structural change not supported by adequate adaptation and risk reduction measures against flooding could result in increasing macroeconomic risks as compared to the baseline scenario.

This potential negative consequence of structural change for macroeconomic risks as compared to a scenario without structural change calls for an increased attention to adaptation measures to extreme wet events in the services and industry sectors. Despite the currently lower contribution to GDP of the services and industry sectors, long-term adaptation and risk management planning would need to integrate progressive changes in countries' macroeconomic structure (Kocornik-Mina & Fankhauser, 2015). In the absence of sound forward-looking adaptation and risk-reduction measures in the industry and services sectors, structural transformation that is already under way in most African countries could lead to an increased macroeconomic vulnerability to the future consequences of climate change.

The effects of climate change on precipitation in Africa are not projected to be homogenous and uniform across African countries. Combined with currently different macroeconomic structures across countries and regions, climate change impacts are projected to lead to diverging risks. More research is needed to reduce the uncertainty in climate projections, as well as in macroeconomic risks estimates, in order to more appropriately understand the potential implications of structural change in African countries. Nonetheless, this preliminary analysis delivers relevant information for climate change-related policy processes:

- The services and industry sectors are most sensitive to extreme and severe wet events, while the agricultural sector is particularly sensitive to extreme dry events;
- Structural change is projected to lead to an asymmetric response, increasing macroeconomic sensitivity to extreme wet events, while decreasing sensitivity to extreme dry events. The cumulative macroeconomic sensitivity is projected to decrease as a consequence of structural change;

- In the absence of adequate adaptation and risk-reduction measures against extreme wet events (floods), some countries, projected to be more frequently exposed to such events, could experience additional negative effects from structural transformation;
- Decisions to be made on adaptation need to integrate future macroeconomic transformation to ensure that societies can harvest the full potential of structural change;
- Even though the share of the agricultural sector is projected to decrease in the coming decades, adaptation measures to extreme droughts are also a pre-requisite to foster African countries' future development.

4.3.4 Regional conclusions and implications

Both low- and high-warming scenarios project strong negative effects on Northern African economies. By 2050 most of these countries could see a significant median decrease in GDP per capita, ranging from 2.5 to 18.6 per cent from the baseline in the high-warming scenario. Even though natural resources have played a strong role in minimizing the consequences of climate-related extremes on macroeconomic indicators (Abidoeye & Odusola, 2015), they might have a limited effect on poverty. Depending on the future prices of oil and gas and the available proven reserves in these countries, these resources may not play their buffering role any longer, or might fall increasingly short. In addition, structural transformation is projected to yield beneficial impacts on Northern African economies with an overall cumulative sensitivity decreasing between 2015 and 2050. However, economies projected to be exposed to an increase in flooding events during the period could experience higher macroeconomic risks, if adequate adaptation and risk-reduction measures are not implemented in the services and industry sectors.

Owing to this rising macroeconomic risk in the region, policymakers may put in place macroeconomic measures and options to anticipate these consequences and improve their ability to cope with their detrimental effects:

- The results of the model as well as earlier studies show that government spending plays a positive role in limiting the spread of negative macroeconomic consequences of climate-related disasters (Yang et al., 2012). However, with the expected recurrence of these events and their increased intensity, Governments would increasingly run the risk of relying on public debt to fund their recovery – potentially raising debt to unmanageable levels, limiting their ability to borrow at an adequate rate on the international market (Kraemer et al., 2015). Options such as public insurance schemes, regional risk-pooling mechanisms or contingency funds could be explored and fostered to prevent these additional negative macroeconomic consequences.
- Trade openness also shows a positive effect on macroeconomic output, also contributing to smooth out the negative consequences of climate-related disasters (Felbermayr & Gröschl, 2013). Temporarily lifting trade barriers in the aftermath of disasters, especially on most necessary goods such as agricultural commodities, construction equipment, etc., could support and accelerate recovery of countries and communities.

- Adaptation and disaster-risk management planning needs to account for the dynamic character of the Northern African economies. Structural change reinforces the need for adequate measures to be implemented to cope with the consequences of flooding events in the services and industry sectors. As also underlined in the chapter on adaptation costs and benefits, ensuring the efficiency of adaptation planning requires accounting for current as well as future economic structures.

4.4 Western Africa – the Sahel and the coastal countries

The Western African region is composed of two climatologically very different subregions: the semi-arid and hyper-arid (desert) Sahel region, from Senegal to the Niger, in the north, and in the south the coastal countries with tropical savannah and tropical monsoon climate (according to the Köppen climate classification). Owing to these large differences in climate, the analysis for these two subregions within Western Africa was done separately. Western Africa is the region with the second largest number of countries: Benin, Cabo Verde, Côte d'Ivoire, Ghana, Guinea, Guinea-Bissau, Liberia, Nigeria, Sierra Leone and Togo in the southern subregion, and Burkina Faso, Gambia, Mali, Mauritania, the Niger and Senegal in the northern subregion.

4.4.1 Current and future socioeconomic and climatic situation

Together with Eastern Africa, Western Africa has the highest share of agriculture in its gross regional product. In 2010, on average 25 per cent of the region's growth originated from agriculture, 22 per cent from industry and 53 per cent from the services sector. In the Sahel countries (Burkina Faso, Niger, Mali, Senegal and Mauritania), the share of the agricultural value added climbs to 28 per cent of the gross product and as high as 41 per cent in Mali and the Niger. With such a large share of GDP coming from agriculture, a sector particularly sensitive to droughts and flooding in countries with limited adaptive capacity, climate-related disasters have led to sizeable GDP fluctuations in the past. The drought that affected Sahel countries in 1973 is the clearest example of this vulnerability. In 1973, agricultural sector output decreased by between 21 per cent in Mali and 12 per cent in the Niger, leading to large reductions in GDP (Berg, 1976). The Sahel countries (6 out of a region of 16 countries) are disproportionately more affected by droughts than coastal countries. According to the EM-DAT database (CRED, 2017), Western Africa was affected by droughts 52 times between 1980 and 2015. Only 19 of these events occurred in non-Sahel Western Africa countries, making Sahel countries almost two times more frequently exposed to droughts than coastal West African countries.

Under a baseline scenario in which climate change does not affect future macroeconomic development, the gross regional product will increase to US\$6.5 trillion (PPP). According to this scenario (same reference as other regions), economies are projected to grow annually between 3.7 per cent (Cabo Verde) and 8.1 per cent (Guinea) from 2010 to 2050. In 2050, Nigeria alone will represent 57 per cent of Western Africa gross regional product, as compared to 65 per cent at present.

The region will face two different climate-change patterns depending on the subregions. In the Sahel, warming would be significantly higher than in the coastal regions in both low- and high-warming scenarios. Although precipitation in the Sahel region

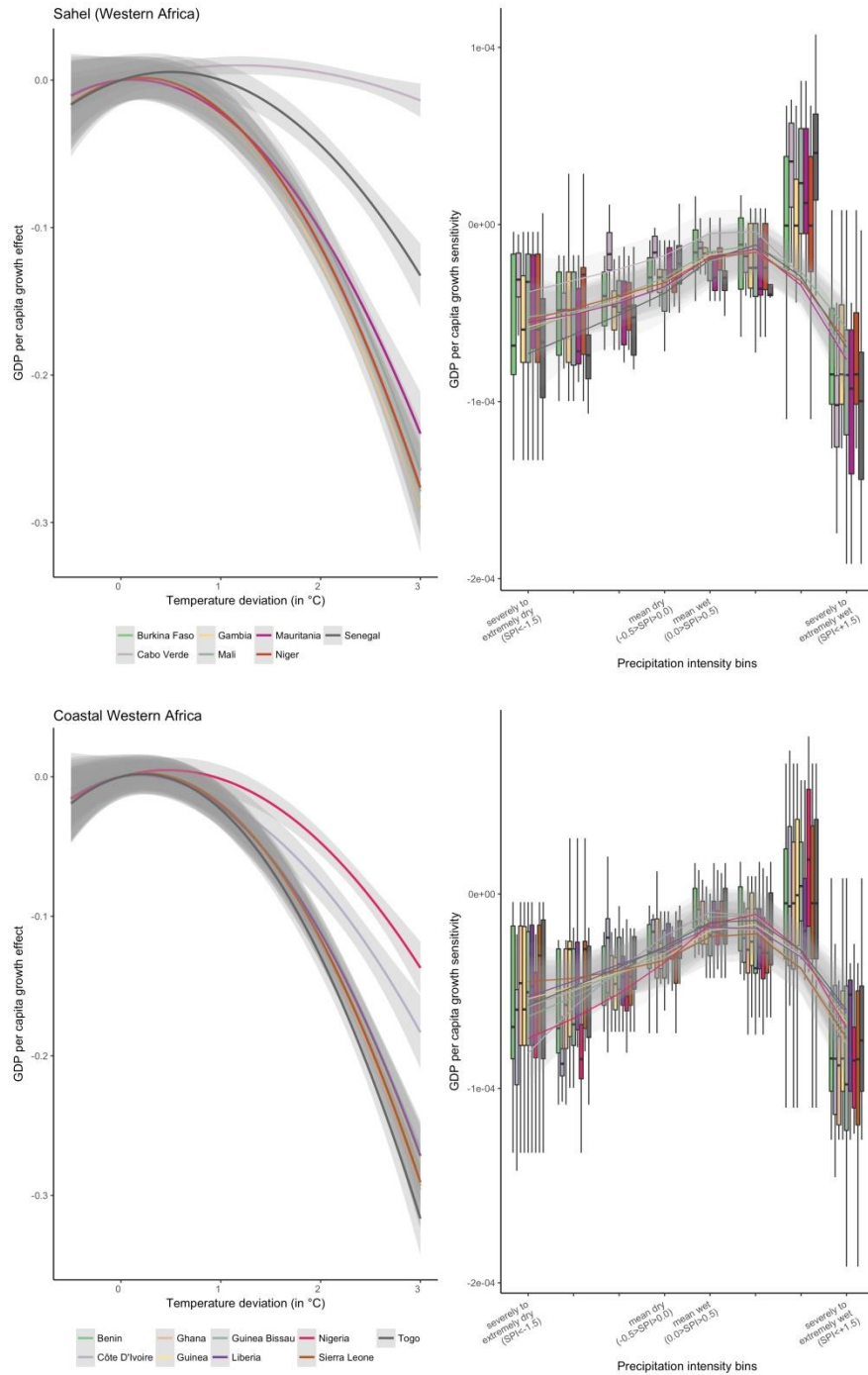
would increase by only a very small amount in absolute terms, this translates into up to 30 per cent over hyper-arid areas in relative terms. For coastal regions, climate models project a limited relative but negative change in precipitation. In the high-warming scenario, the coastal regions start experiencing a progressive decrease in precipitation from about 6–12 per cent as compared to present-day mean precipitation. In the same high-warming scenario, the small increase in precipitation in the Sahel countries concerns mainly the landlocked countries of Western Africa, but Senegal and the western part of Mali become slightly drier.

4.4.2 Macroeconomic risks

Sensitivity of the economy to climate stressors

As discussed above, the coastal and Sahel countries of Western Africa have very different climates and have been differently affected by climate-related disasters in the past, especially droughts. Countries included in the Sahel group are the Western African Sahel countries. The Sahel countries display a pattern of sensitivity similar to Southern African countries – negative sensitivity to both extreme dry and extreme wet events (Figure 12, right panel). This pattern highlights the extreme sensitivity to precipitation extremes of the Sahel economies. Such a high sensitivity leads to high risks from climate change, but also implies that uncertainties in climate projections are strongly amplified when transferred to GDP per capita risk projections. The sensitivity to changes in temperature divides the countries into three different categories: Cabo Verde, with rather limited sensitivity, Nigeria, Senegal and Côte d’Ivoire with medium sensitivity, and finally the rest of the Western African countries with high sensitivity to temperature changes. The situation of Senegal is particularly worthy of investigation, as the limited sensitivity to temperature changes is compensated by a larger than average sensitivity to extreme dry events.

Figure 12 Temperature effect (left panel) and precipitation sensitivity of Western African economies for the period 1980-2014. The upper panel is for the Sahel Western African countries and the lower panel is for coastal Western African countries. Source: authors’ calculations based on the econometric-based macroeconomic forecast model described in Box 2 and Annexes.



The relationship between precipitation extremes and macroeconomic output in the coastal countries of Western Africa is rather similar to the sensitivity of the Sahel countries (Figure 12). However, the positive sensitivity to above mean precipitation climate is significantly higher in the Sahel countries than in coastal countries. It shows that even extreme dry events might have a similar influence on these countries' economies, while Sahel countries produce more effectively when precipitation is above normal.

While changes in precipitation may have little effect on coastal countries, Sahel countries are strongly dependent on them. However, both subregions exhibit strong negative responses to temperature increase.

Future effects on GDP

Cabo Verde is the only Western African country whose economy could eventually have limited losses from climate change in low- and high-warming scenarios by mid-century (with the caveat that the forecasting ability of the model is more uncertain in small-size countries, particularly islands). In the low-warming scenario, Sahel countries are projected to experience a slight increase in precipitation, albeit with low agreement among climate models. This increase could lead to a positive effect on their macroeconomic output in the near term, although in the other Western African countries the negative effects of increases in temperature surpass the effects of the small projected increase in precipitation. We note that the apparently subtle balance between negative and positive precipitation and temperature effects leads to GDP signals that might be counter-intuitive and/or transient, and are subject to considerable uncertainty. In the high-warming scenario, with the exception of Burkina Faso and the Gambia, all Sahel countries could be negatively affected, as even the effects of the small increases in precipitation across Sahel countries are trumped by the rapid increase in temperatures.

The uncertainty surrounding the positive effects in the near or longer term for Burkina Faso, the Gambia, Guinea-Bissau (low-warming scenario), Mali (low-warming scenario), the Niger and Senegal (low-warming scenario) is much larger than the uncertainty of the negative effects on other countries (see the annex, figure A2.3). For Burkina Faso, in 2050, the likely uncertainty range spans about 20 percentage points and in Guinea-Bissau about 40 percentage points, while uncertainty in negative effects is generally around 5 percentage points. Considerable uncertainty originates from the disagreement between the selected climate models with respect to the future effects of climate change on the Sahel countries, especially regarding precipitation, which is amplified by the Sahel region's sensitivity of GDP growth to precipitation anomalies.

In the high-warming scenario, almost all countries in Western Africa are negatively affected. The scenario projects almost no effect for Burkina Faso but very strong negative effects in Senegal with a decrease of 40 per cent as compared to the reference GDP scenario. The Gambia still displays a positive effect but with a large uncertainty range (from +10 to +25 per cent). This considerable uncertainty is an additional cause for concern, as developing adaptation policy in conditions of high uncertainty is a major challenge.

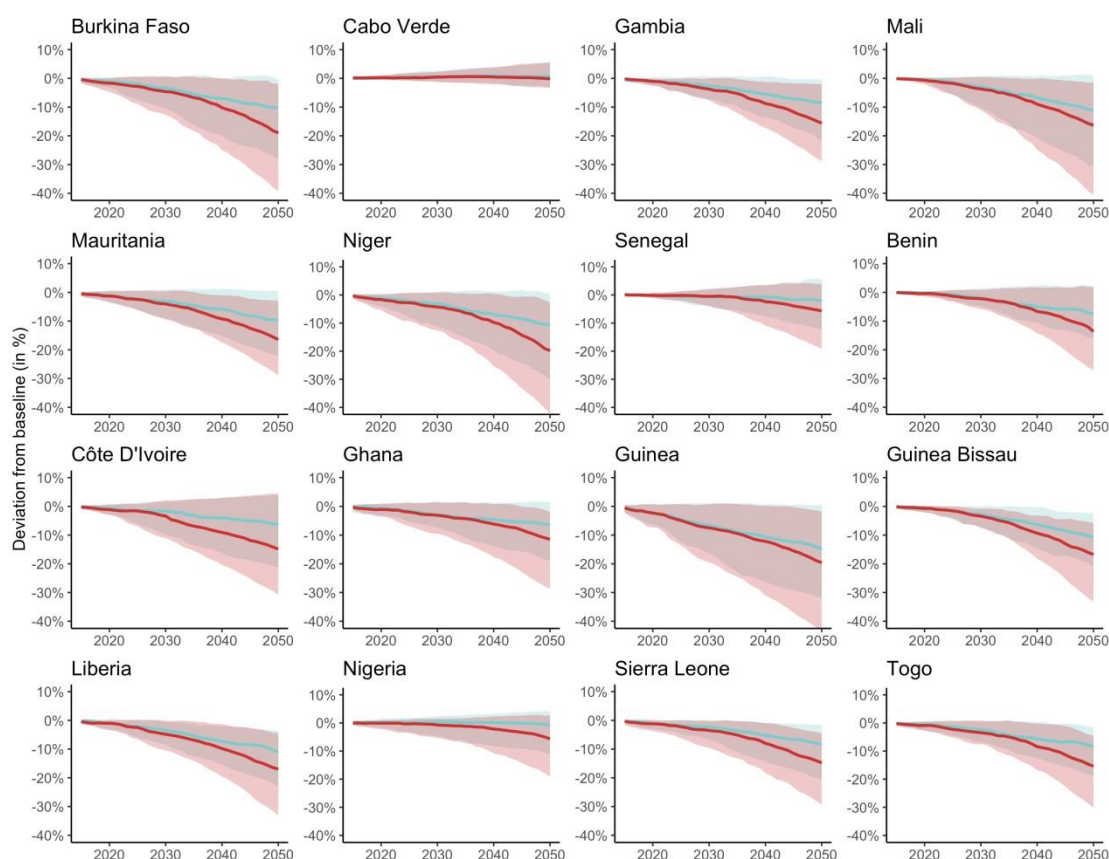


Figure 13 GDP per capita change in a below 2°C (blue) world and above 4°C (red) world as compared to a non-climate change scenario (SSP2) for Western African countries for the 2015-2050 period. The range represents the 66 per cent statistical confidence interval, while the line shows the medians of all risk estimates. Authors' calculations are based on the econometric-based macroeconomic forecast model described in Box 2.

The coastal countries of Western Africa would experience macroeconomic consequences as early as 2030s in both scenarios. In the low-warming scenario Guinea, Liberia and Ghana would be most affected with possible negative effects ranging from -2.8 (Ghana) to -6.6 per cent (Guinea) below the baseline in 2030. More significant negative macroeconomic effects would emerge by the 2050s, with macroeconomic output dropping from -6.4 (Côte d'Ivoire) to -14.7 (Guinea) per cent below the baseline scenario. In the high-warming scenario, among the region's southern coastal countries, Guinea (-19.6 per cent), Liberia (-16.9) and Guinea-Bissau (-16.7) would be most affected. In the coastal Western African countries, Nigeria particularly stands out on account of its limited macroeconomic impacts. By 2050, macroeconomic impacts would range from close to 0 per cent change in the low-warming scenario to about -5.6 per cent in the high-warming scenario. These limited impacts in Nigeria again illustrate the buffering effects of natural resources (here oil) on the effects of climate-related events on macroeconomic outputs.

The Sahel countries are projected to be amongst the most affected countries of Africa. The Gambia, Mauritania, Burkina Faso, the Niger and Mali could face losses in GDP per capita higher than 15 per cent by 2050, which could be as high as 19.8 per cent for the Niger, in the high-warming scenario. Benefiting from a slower increase in temperature along the coast, where most of its economic activities are located, Senegal would be exposed to about 5.7 [-16.0;1.1] per cent decrease in GDP per capita. In the low-warming scenario, the negative impacts of climate change would be almost halved

as compared to the losses in the high-warming scenario, with losses ranging from 8.4 (the Gambia) to 11.1 (Mali) per cent. Owing to the considerable disagreement among climate models in the Sahel region, the uncertainty in the estimates is particularly large. For example, the 50 per cent statistical confidence interval for Burkina Faso, Mali and the Niger spans about 30 percentage points – among the largest of all African countries. If the 95 per cent confidence interval is taken into account, this spans approximately 70 percentage points in the high-warming scenario – ranging from about -50 per cent to +20 per cent, in these three countries and including Senegal (confidence spanning 50 percentage points).

4.4.3 Regional conclusions and implications

How future climate will affect the Sahel countries remains uncertain, and both negative and positive consequences could be expected for these countries. The uncertainty of climate projections makes policy- and decision-making in this area even more intricate, as adapting to an increasingly drying trend requires adaptation options and strategies different from adaptation to a wetting trend. Furthermore, even though some countries are expected to become wetter, this could also be accompanied by flooding events, which would also have a negative effect on development, macroeconomic output and fiscal balance.

Temperature increase would have the most significant impact on the coastal countries but unprecedented extreme dry and extreme wet events could also cause more damage in the future. This analysis has limited ability to appropriately factor in the effects of precipitation extremes on the Western African coastal countries and should be regarded as conservative.

In addition to being a vulnerability hotspot (Ben Mohamed, 2010), the Sahel region is also a hotspot for uncertainty regarding future climate. Regional policymakers may request more research and information to inform their policies. In the absence of a clearer understanding of the precipitation trend expected in these countries, policymakers run the risk of implementing adaptation options that could turn out to be ill-adapted. In such cases, an appropriate strategy would be to focus first on no-regret interventions that provide early adaptive benefits for dry and wet events and extremes. In addition, the design of risk transfer mechanisms could account for both extreme dry and wet events, as well as anticipating the strongest effects of future temperature increases, including on health as well as the agricultural sector.

4.5 Eastern Africa

Eastern Africa¹⁴ covers three distinct climatic zones: semi-arid and hyper-arid (desert) climate of the Sahel region in the north for Djibouti, part of Ethiopia and Eritrea; tropical savannah climate in Burundi, Rwanda and Uganda; and humid subtropical climate in parts of Mozambique and Zimbabwe. The region is a patchwork of climates, with stronger and weaker influences from the Indian Ocean. Examples of this climatic diversity are Ethiopia and Madagascar, which count at least five different climates according to the Köppen classification. In recent decades, the region has experienced severe droughts, for example, currently in 2016-2017, in the Horn of Africa in 2011 (Zaracostas, 2011) and even more dramatically in 1983-1985 in Ethiopia, which has led to widespread famine (Gebrehiwot & van der Veen, 2013). Even though the countries of the region have improved their coping capacity, past decades show that climate-related disasters still have the potential to undermine macroeconomic output and development at the regional level.

4.5.1 Current and future socioeconomic and climatic situation

Eastern Africa's gross regional product was US\$143.8 billion in 2012, with 28 per cent originating from the agricultural sector, 21 per cent from the industry sector and 51 per cent from the services sector. There are large disparities with respect to the share of agriculture in the national product between countries within the region. Mauritius and Seychelles are island-State outliers deriving only 3 per cent of their GDP from agriculture but the agricultural sector of Burundi and Ethiopia makes up 40 per cent of their GDP. Ethiopia, the United Republic of Tanzania and Kenya combined account for half the gross regional product. In a manner similar to Western African countries, such a large share of agricultural value added constitutes a high macroeconomic susceptibility to climate-related shocks, especially droughts. Research shows that droughts have had detrimental consequences on these countries' macroeconomic indicators and development in the past (S. Barrios et al., 2010; Zaracostas, 2011).

Under a baseline scenario in which climate change does not affect future macroeconomic development, the gross regional product will reach US\$3.8 trillion (PPP). According to this scenario (same reference as for other regions), economies would grow per annum between 3.1 per cent (Mauritius) and 5.9 per cent (Uganda) from 2010 to 2050.

Eastern Africa could experience two distinct precipitation trends resulting from future climate change. Global climate models project a progressive wetting in the northern countries, including Ethiopia and northern Kenya, with annual precipitation increase of 12 to 18 per cent as compared to present-day levels in the low-warming scenario, and as much as 18 to 30 per cent in the high-warming scenario. By contrast, countries in the southern region could face a 6 to 12 per cent precipitation reduction in both scenarios. Temperatures will increase uniformly throughout the region; by 1.6°C to 1.8°C in the low-warming scenario and by over 2.2°C in the high-warming scenario by 2050 as compared to the present day.

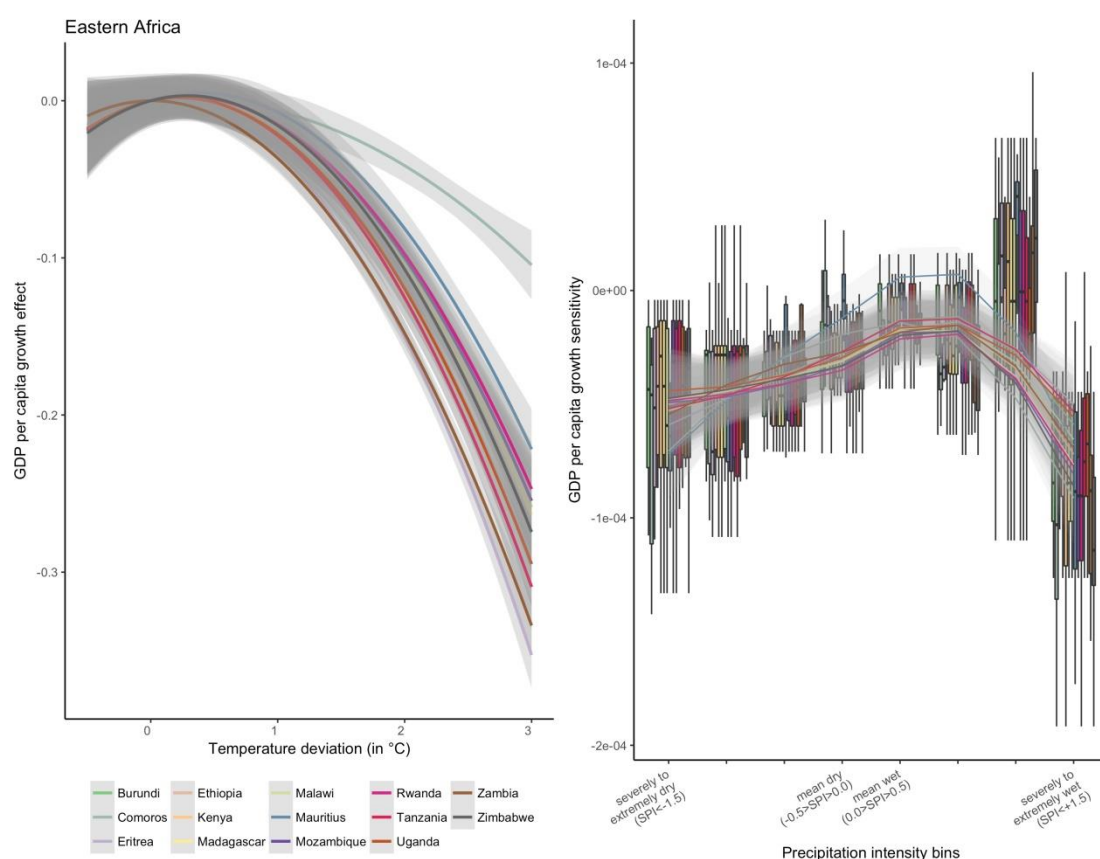
¹⁴ This region includes the following countries: Burundi, Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Madagascar, Malawi, Mozambique, Rwanda, Seychelles, Somalia, South Sudan, Uganda, United Republic of Tanzania, Zambia and Zimbabwe.

4.5.2 Macroeconomic risks

Sensitivity of the economy to climate stressors

Like most African countries, Eastern African countries show a strong sensitivity to extreme dry events owing to a combination of economic and climatic factors – a large GDP share of agricultural value added and the occurrence of intense, long droughts. The sensitivity of the Eastern African countries is comparable to the Sahel and Northern African countries. In addition to extreme dry events sensitivity, the countries of the region are equally susceptible to extreme wet events.

Figure 14 Temperature effect (left panel) and precipitation sensitivity of Eastern African economies for the period 1980-2014. Source: authors' calculations based on the econometric-based macroeconomic forecast model described in Box 2.



Temperature rise also strongly affects Eastern African countries. Similar to what is seen in the other regions, the optimal temperature ranges between 0 and 1°C; the Comoros could be relatively less sensitive than the rest of Eastern African countries.

Box 3 Micro-Macroeconomic Transmission Mechanisms and Channels of Consequences of Climate Change: Case of Ethiopia

Workneh Negatu,¹⁵ Addis Ababa University, and Sindu Kebede,¹⁶ Humboldt University

Despite the remarkable economic growth that Ethiopia has achieved in recent years, gradual climate change and variability are undermining progress in achieving food security and poverty alleviation. The common climate-related disasters (CRD) in Ethiopia are mainly drought and flooding. Drought occurred almost every 2-3 years in the 1980s, 1990s and 2000s (CRED, 2017). Climate-related disasters thus have an effect on both micro- and macroeconomic outcomes. This analysis aims to understand the pathways and mechanisms of micro-level effects of climate variability on the macroeconomy and vice versa, and pinpoint policy implications of the findings. For this, we employed both qualitative and quantitative methods in which a critical review and assessment of the available literature and data is conducted to address the objectives.

Reduced crop yields and crop failures occur often because of extreme weather events with an overall effect of shortage of food and food insecurity as well as declines in income of agricultural and pastoral-based households (Brown et al., 2010). In addition, extreme weather events, such as droughts and floods, lead the Government to spend on emergency provisions for the affected population, which increases its expenditure unexpectedly and shifts government expenditure away from basic services such as health, education and expansion of the extension system (Benson & Clay, 2004). At the same time, incidences of extreme events lead to reductions in government revenue, which are caused by slowdown of the private sector during extreme events (Benson & Clay, 2004). Similarly, declines in agricultural food production result in shortage of food supplies on the market, leading to inflation, and food price inflation in particular (Berg, 1976). The overall effect could create an imbalance in the macroeconomy of the country.

The study investigates whether the Government of Ethiopia covers climate-related disaster expenditures and overcomes macroeconomic imbalances by taking loans on the international market. This would lead to an increase in government debt, making goals of planned national poverty reduction strategies more difficult to reach. These hypotheses are supported by the quantitative analysis, where it is observed that extreme dry (SPI values below -1.5) and extreme wet events (SPI values above 1.5) result in an increase in government debt. Hence, our results show that debt could act as a “buffer” against the effects of climate variability on GDP growth. From the microeconomic variables, we find that school enrolment declines in response to occurrence of extreme dry events – but not in response to extreme wet events (potentially linked to their shorter time frames of occurrence). Consequently, children are forced to drop out of school, leading not only to a reduction in the children’s future income and livelihood path, but also to an overall reduction in human capital at the national level. Decrease in national level human capital can lead to a long-term decline in overall rate of productivity of the country and puts a strain on one of the major economic development instruments, namely, education.

Finally, the overall effect of various impacts of extreme weather events on micro- and macroeconomic outcomes is an increase in poverty rates in Ethiopia and a decline in GDP. Especially, the country’s GDP is found to respond promptly to drought. It is noted that some of the more substantial declines in GDP growth over the past three and half decades have occurred during major drought years. For instance, national GDP and agricultural GDP declined by 9.7 and 21 per cent respectively during the

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1984/5 droughts. Therefore, the Ethiopian analysis finds that the connection between national GDP, agricultural GDP, poverty, food insecurity and drought is direct and visible. The underlying causes of this relationship seems to point towards food production and productivity; drop in school attendance; in-country migration; human and livestock disease; external debt; and inflation.

The study points out the following policy implications for the agricultural sector:

- Mitigation measures, such as afforestation and protection of vegetation cover and environment, as well as expanding energy from renewable resources are strategic measures, which are also emphasized within the Climate Resilient Green Economy (CRGE) strategy of Ethiopia.
- In order to reduce the impacts of droughts on water availability, measures contributing to developing water sources are essential.
- -value crops, drought-tolerant crop varieties (which need to be developed by an agricultural research system), and engagement in non-agricultural economic activities, for which different programmes need to be promoted by the Government, non-governmental organizations and communities.
- Another policy-oriented implication is to strengthen the development of market-based coping strategies such as index-based insurance systems to serve as “buffer” for farmers against unforeseen extreme events, for example droughts.

Any decline in agricultural growth has a direct impact on the national GDP. The macroeconomy’s effort and capacity to handle negative effects of climate variability at microlevel reduces its investment capacity for long-term development interventions and current expenditure for various sectors of the economy. In this regard, making all efforts to strengthen its economic and financial resilience with appropriate strategies is essential. These include strengthening the Climate Resilient Green Economy (CRGE) strategies adopted by the Government, promoting export markets particularly high-value horticultural and livestock products and facilitating and further encouraging the involvement of private sector in domestic and foreign trade and in production sectors.

At the macroeconomy level, adopting a preventive strategy against the negative consequences of extreme weather conditions by promoting and supporting mitigation strategies at the ground level (by creating awareness and attitudinal change about use of forest, land, water and biodiversity) is of paramount importance. Similarly, developing extensive early warning mechanisms to alert farmers about the occurrence of extreme weather conditions and ensure that farmers receive weather information on time regarding, for example, drought or untimely rains that destroy harvest, would also contribute to limiting the negative consequences of climate-related disasters at the microeconomic level.

Future effects on GDP

As a consequence of climate change, Eastern African countries will undergo a slow and steady decrease in their domestic products per capita if no adaptation measures are implemented to cope with these consequences from the micro- to macroeconomic levels.

By the 2030s, most the countries of the region, except Burundi, the United Republic of Tanzania and Zimbabwe, are projected to experience a below 5 per cent decrease in

their GDP growth and hence in their GDP, as a consequence of increasingly non-optimal climate conditions. In the high-warming scenario, this effect will remain limited – between 0.7 (Comoros) and -4.9 (Rwanda) per cent as compared to GDP levels in a non-climate change scenario. By the 2030s, the macroeconomic effects of the two warming scenarios start diverging in most countries of the region, with the exception of the island States of the Indian Ocean, where the deviation remains marginal. Ethiopia, one of the main economic powerhouses of Eastern Africa, could experience notable losses in terms of GDP per capita as early as 2030, with a projected decrease in both scenarios around 3.8 per cent. The United Republic of Tanzania and Kenya would be more severely affected with projected losses between 6.0 and 4.4 per cent in the high-warming scenario.

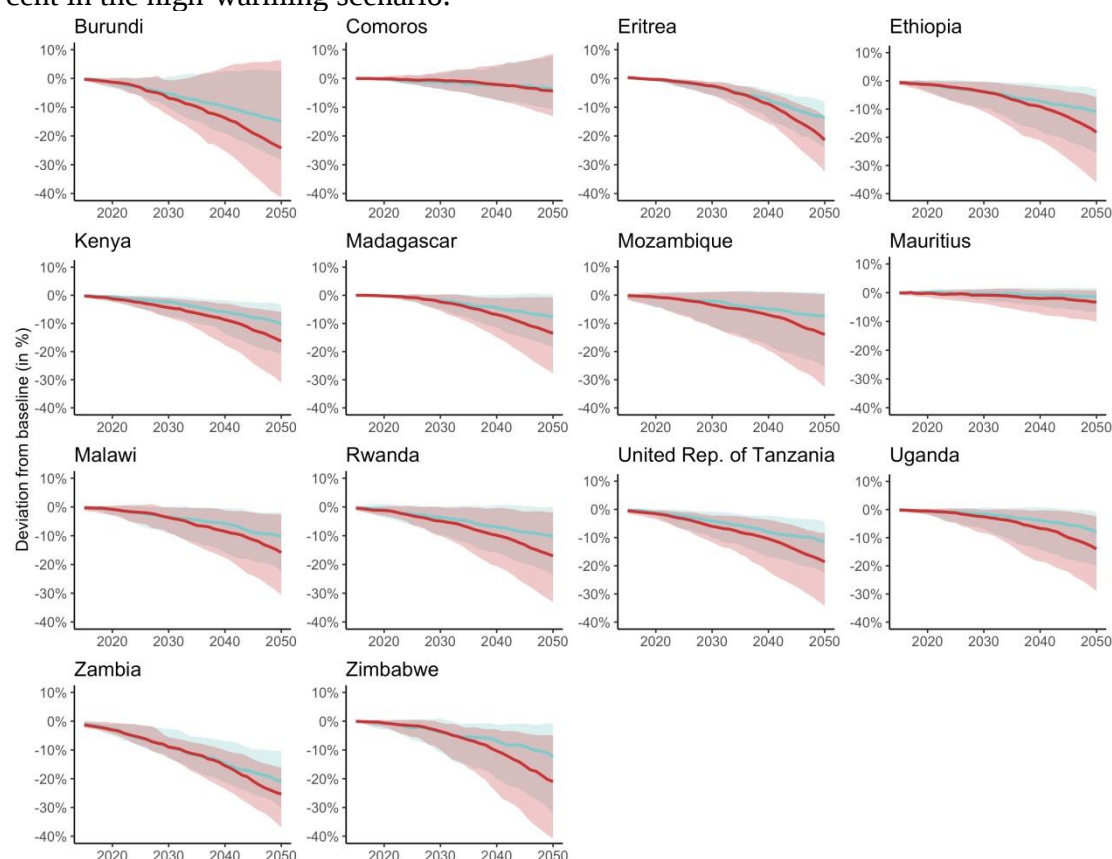


Figure 15 GDP per capita change in a below 2°C (blue) world and above 4°C (red) world as compared to a non-climate change scenario (SSP2) for Eastern African countries for the 2015-2050 period. The range represents the 66 per cent statistical confidence interval, while the line shows the medians of all risk estimates. Authors' calculations are based on the econometric-based macroeconomic forecast model described in Box 2.

By mid-century, in the low-warming scenario, all countries are affected in various degrees. GDP per capita losses are projected between -1.3 per cent in Mauritius and -13.7 per cent in Zimbabwe. Eastern Africa's three powerhouses (Ethiopia, Kenya and the United Republic of Tanzania) could be exposed to losses amounting to about 10 per cent. Such high losses for these three countries highlight their current vulnerability to climate variability and weather extremes combined with future rapidly changing precipitation and temperature patterns. The high-warming scenario further amplifies

the risks measured in the low-warming scenario, with losses ranging from -3.3 (in Mauritius) to -25.3 (in Zambia¹⁷).

4.5.3 Regional conclusions and implications

Eastern and Western Africa are projected to be the most affected regions of the continent. At the regional level, in the low-warming scenario, the median loss in GDP per capita could be about 9.9 per cent (50 per cent probability range -3.3; -18.6 per cent), and in the high-warming scenario, 16.0 per cent (50 per cent probability range -6.7; 26.7 per cent) by 2050.

Furthermore, other publications have found that climate change could increase the number of undernourished people in Eastern and Southern Africa by 50 per cent by the 2030s (Funk et al., 2008). However, these researchers estimate that a “modest increase in per-capita agricultural productivity” could contribute to offsetting the negative consequences of precipitation and temperature changes. Preventing the impacts of spreading from the microeconomic to the macroeconomic levels, and vice versa, will require the implementation of adequate resilient development measures in all sectors of the economy and society. In addition, macroeconomic measures can help accelerate the recovery process in the aftermath of climate-related disasters, for example suspending remittances fees or temporarily removing trade barriers for imports of emergency items such as food and reconstruction equipment.

4.6 Central Africa

Central Africa is located in the middle and western part of Africa, neighbouring all four other African regions, as defined by the United Nations. The region includes Angola, Cameroon, the Central African Republic, Chad, the Congo, the Democratic Republic of the Congo, Equatorial Guinea, Gabon and Sao Tome and Principe. It is climatically diverse, with climates ranging from desert in the north of Chad to tropical rainforest in the Congo Basin. The region has experienced great political and social instability in the recent past. Between 1980 and 2014, the region experienced at least 80 years of international armed conflict, a total of 270 country-years (Pettersson & Wallenstein, 2015). The high number of armed conflicts limits the reliability of the following analysis as reliable macroeconomic data are often not available or could be affected by conflict aftermath, or conflicts in neighbouring countries.

4.6.1 Current and future socioeconomic and climatic situation

The great majority of Central African countries are exporters of natural resources. Angola, Chad, the Congo, Equatorial Guinea and Gabon are oil exporters, and the Democratic Republic of the Congo is also an exporter of rare minerals such as gold, uranium and diamonds. The exploitation of these resources explains why the share of

¹⁷ Even though the model accuracy for Zambia is high, in comparison to the other African countries, only three years of observations are available to calibrate the model results. Therefore, the results for Zambia need to be interpreted carefully.

the industry sector is so dominant in these countries. The industry sector accounts for 55 to 75 per cent of value added in Angola, the Congo and Gabon. However, a small number of countries rely heavily on agriculture. For example, the Central African Republic derives about 55 per cent of its GDP from the agricultural sector, similarly to Chad with 52 per cent. At the regional level, the industry sector accounts for 48 per cent, services 35 per cent and the agricultural sector 17 per cent of value added. In 2010, the gross regional product was \$122 billion, of which approximately 45 per cent was generated by Angola.

Trade in natural resources contributes to lessening the negative macroeconomic consequences of climate-related disasters. The agricultural sector still represents a large share of the regional product but the limited quality and coverage of macroeconomic data means that the effects of past climate variability are less traceable than in any other African regions.

By 2050, the gross regional product is projected to be \$1.7 trillion – with an average growth rate of 5.1 per cent. Chad, the Democratic Republic of the Congo and Sao Tome and Principe are expected to experience the highest growth, with an average growth rate per annum between 7.1 and 8.5 per cent (Dellink et al., 2015).

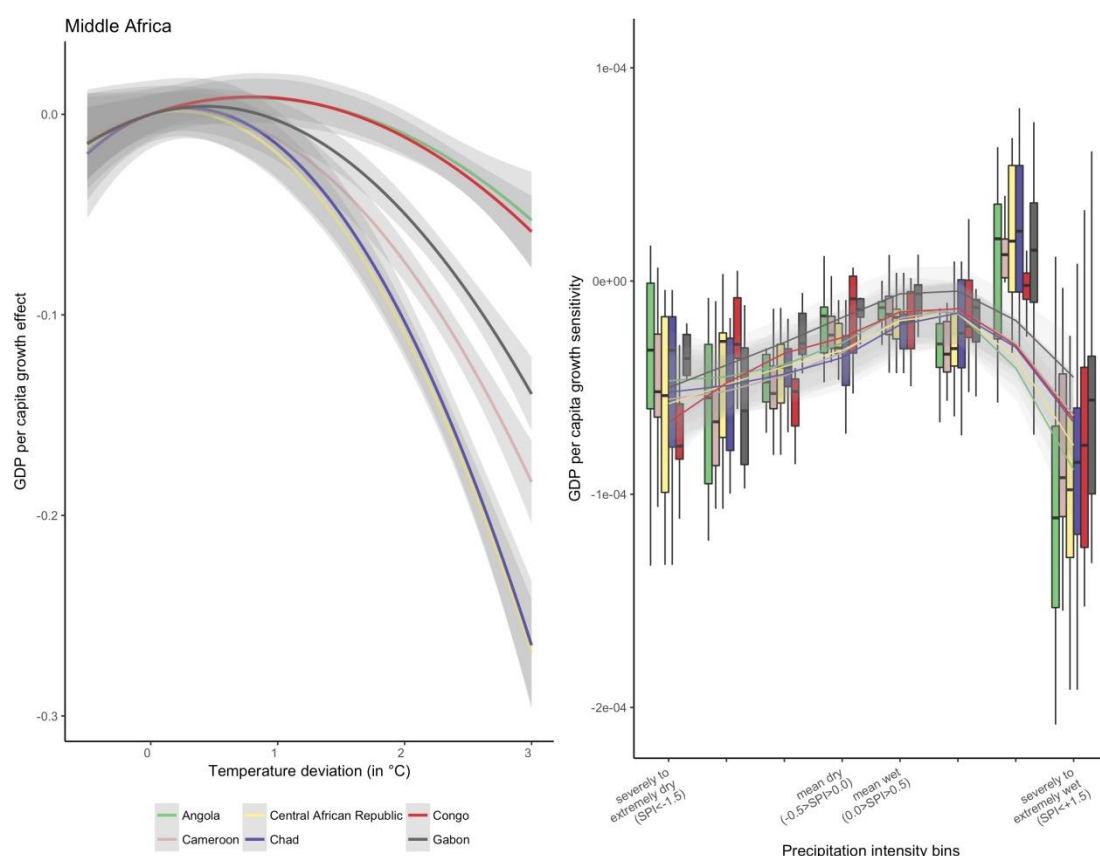
Central Africa is likely to experience the least absolute change in temperature and precipitation of all African regions. The low-warming scenario projects temperature increase of about 1.2°C to 1.8°C, with the strongest warming in northern Chad. Precipitation would remain at current levels ranging between -6.0 and +6.0 per cent by 2050, as compared to the present day. The high-warming scenario projects precipitation to stay in the same range as the low-warming scenario and temperatures to rise by 1.6°C to 2.2°C by 2050, as compared to the present day. Northern Chad, part of the Sahel region, will experience a temperature increase of more than 3°C.

4.6.2 Macroeconomic risks

Sensitivity of the economy to climate stressors

Central Africa displays a similar sensitivity pattern to Southern Africa. Both extreme dry and extreme wet events have the potential to affect macroeconomic output. However, Central African economies are slightly more sensitive to extreme wet events than dry events. The spread of risk for extremes is large, spanning from -0.03 to +0.00 for extreme dry events and from -0.01 to -0.02 for extreme wet events, showing a very strong sensitivity to extreme wet events. The uncertainty surrounding the degree of sensitivity largely originates from the lack of available and reliable macroeconomic data for the region. For this reason, the overall results for the Central African region need to be interpreted with great care.

Figure 16 Temperature effect (left panel) and precipitation sensitivity of Central African economies for the period 1980-2014. Source: authors' calculations based on the econometric-based macroeconomic forecast model described in Box 2 and Annexes.



Like precipitation, temperature change also has negative consequences for countries' macroeconomic outputs. In Central African countries, a 1°C warming above the historical mean has been associated with a decrease of about 0.7 percentage point of GDP growth, ranging from -1.3 to -0.03. It is also worth noting that the region has experienced a very limited number of heat extremes during the last 40 years. For this reason, the model has only a limited capacity to infer the effects of heat extremes on the economy.

Future effects on GDP

On average, the future climate of the region is projected to change less drastically than in any other African region. However, the region is projected to be increasingly exposed to extreme wet and dry events, which would lead to decrease GDP growth in the years when they occur and would generate long-lasting negative impacts in subsequent years (Dell et al., 2012b).

By 2030, the temperature deviations between the low- and high-warming scenarios start bringing discernible effects on the countries. In the high-warming scenario, the average loss of GDP spans between -0.1 (Congo) and -3.4 (Central African Republic) per cent. In the low-warming scenario, GDP would decrease by as much as 2.6 per cent, particularly in Cameroon, the Central African Republic and Chad.

Moving to 2050, the Central African Republic and Chad would experience the highest GDP per capita decrease in the region, ranging from -7.9 per cent in Chad in the low-warming scenario and about 16.9 per cent in the Central African Republic in the high-warming scenario but with relatively high uncertainty (spanning from -8.1 to -23.7 per

cent decrease for the high-warming scenario). In the high-warming scenario, Angola and the Congo would experience very limited losses due to climate change and variability – highlighting again the buffering effect of natural resources on the economy of the countries.

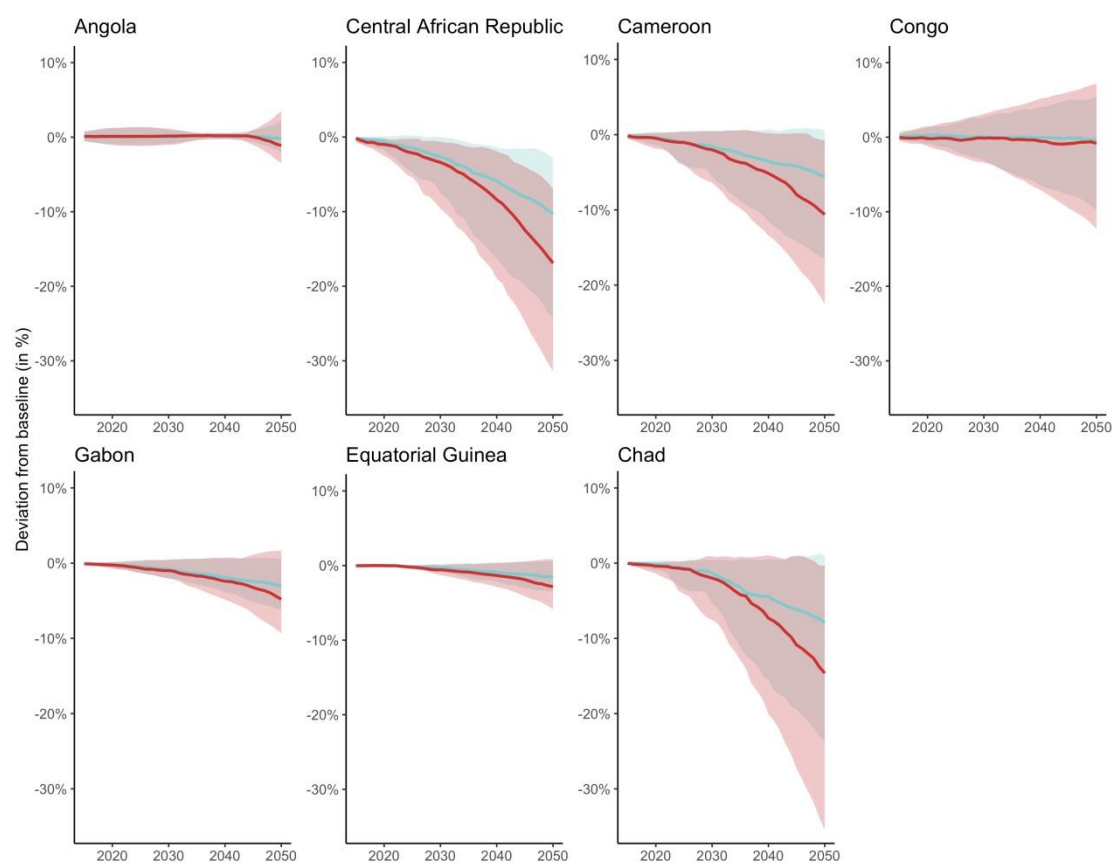


Figure 17 GDP per capita change in a below 2°C (blue) world and above 4°C (red) world as compared to a non-climate change scenario (SSP2) for Central African countries for the 2015-2050 period. The range represents the 66 per cent statistical confidence interval, while the line shows the medians of all risk estimates. Authors' calculations are based on the econometric-based macroeconomic forecast model described in Box 2.

By 2050, for Central African countries, in the low-warming scenario, the median risk to GDP per capita would be about -2.4 in the low-warming scenario (0.1 to -7.7 per cent for the 50 per cent statistical confidence interval) lower than in the baseline scenario. In the high-warming scenario, median GDP per capita risk for all the countries of the regions would be lower by about -4.8 per cent (-0.6 to -12 for the 50 per cent statistical confidence interval).

The model estimates that in both scenarios Angola would sustain limited macroeconomic consequences. This limited risk to GDP per capita could either arise from the minimal changes in weather patterns over the most productive areas (along the coastline), or from the modelling approach which consists in applying a risk as a percentage of GDP per capita growth. Indeed, in the baseline scenario used for the analysis (here SSP2), Angola is projected to experience negative GDP per capita growth in the 2020s and overall low growth throughout the period.

4.6.3 Regional conclusions and implications

Central Africa is projected to be less affected by climate change than other regions. However, individual countries, such as the Central African Republic and Chad – already amongst the poorest countries of the region – are still estimated to face large macroeconomic losses (with high uncertainty). A further limitation of the macroeconomic consequences will require strong adaptation and disaster-risk reduction measures to anticipate and cope with the projected climate change impacts. Measures at the macroeconomic level, such as increasing trade openness and facilitating the inflow of remittances, can also be implemented to accelerate recovery following climate-related disasters. Inflow of international public assistance has also been associated with a positive effect on macroeconomic output.

4.7 Conclusions and recommendations

4.7.1 Conclusions

There are many reports and studies concerned with the economic impacts of climate change, globally, on the developing world and on Africa. This report is an important step in further developing a scientific and economic appraisal of the effects of climate change on African economies. This chapter's findings are generated by a novel method that effectively combines climate observations and climate model projections for precipitation and temperature with historical socioeconomic data to estimate future change in macroeconomic output in African countries. The approach also allows for better integration of the effects of climate-related disasters in economic assessments by defining whether they occur in heavily-populated areas.

Until now, the differential impacts of climate change between the low- and high-warming scenarios were expected to occur after the 2030s, when temperature trends in the respective scenarios start diverging. The analysis conducted for this report based on the two warming scenarios of IPCC¹⁸ (RCP2.6 and RCP8.5), however, indicates that the divergence in impacts could occur earlier in the century, further highlighting the need for increased pre-2025 and pre-2030 emission reductions.

Changes in precipitation patterns and extremes, and changes in temperature are projected to have negative consequences for African countries' GDP. Furthermore, climate-related disasters could increase pressure on national Governments and budgets. The Ethiopia case study finds that dry and wet extremes have the potential to increase government debt level. Similarly, the 1991–1992 droughts doubled Zimbabwe's current account deficit and increased external debt level from 36 per cent prior to the dry spell, 60 per cent in 1992 and a staggering 75 per cent in 1995, as government expenditures increased in order to fund emergency relief (IMF, 2003; Stern, 2006). Similarly, Yang et al. (2012), studying the Republic of Korea, found that climate-

¹⁸ In the RCP2.6 and RCP8.5 scenarios, emissions already start to diverge in 2005, over 10 years ago. As a consequence, a divergence in impacts between those two scenarios between 2015 and the 2030s is only a proxy for “real” projected divergence in macroeconomic impacts between the low and high scenarios already starting today.

related disasters could trigger government spending shocks, which are financed through non-tax revenues, such as sales of public enterprise stocks or by government debt.

Therefore, as a consequence of climate-related disasters, government revenues may drop while expenditures steeply increase, forcing the Government to rely on external debt to fund post-disaster relief and its activities. This combination of consequences could lead to downgrading of creditworthiness, thus further increasing credit cost and possibly limiting the ability to borrow in the international market. The rating agency Standard and Poor's (Kraemer et al., 2015) estimated that climate-related disasters could significantly downgrade government ratings;¹⁹ e.g., Dominican Republic lost 2.5 notches in the case of tropical cyclones, and Thailand 1.5 notches due to flooding events.

4.7.2 Recommendations

Based on the main findings in this chapter, a set of core recommendations could be considered by climate and economic decision-makers in Africa and on the global level.

1. Climate change is projected to put an increasing pressure on government budgets and macroeconomic development. This additional constraint needs to be integrated in development planning and strategies. Tools with the ability to connect climate and macroeconomic indicators need to be made available to the relevant national, regional and continental organizations in charge of macroeconomic forecasting and planning. A number of practical actions could be put in place to foster the integration of climate change in macroeconomic development planning and government budgeting:
 - (a) The African Economic Outlook, published every year by the African Development Bank, could integrate a five-year and longer-term update on climate-induced macroeconomic risks to which countries are projected to be exposed.
 - (b) Capacity-building of experts in statistical and meteorological offices is needed in order to more appropriately combine and analyse climate and socioeconomic data. Collaboration between these offices and the ministry in charge of planning and forecasting could also be strengthened.
 - (c) Climate and socioeconomic data, as well as tools to analyse historical and future climate risks need to be made available to government experts on an open-access basis when they serve useful public purposes.
2. At the national level, Governments need to develop (or foster already existing) adequate financial instruments to manage macroeconomic risk by retaining an acceptable level, transferring excessive risk, and finding the most optimal allocation of their resources. Some actions toward this objective could include:
 - (a) Further strengthening initiatives like the African Risk Capacity to account for this increasing climate risk to macroeconomic development and government budgets.
 - (b) Risk-management solutions involving the public and the private sectors could be implemented, such as emergency relief funds, insurance and micro-insurance schemes. Efforts on the prevention of climate-related disasters,

¹⁹ The study does not include African countries.

including early-warning systems, could be put forward using latest technical solutions such as real-time satellite imagery, seasonal forecasts, etc.

3. The report suggests that structural change under a changing climate must go hand in hand with infrastructural improvements that increase resilience of industry and services to extreme wet events, such as early-warning systems, better drainage systems, improved urban planning, etc. Above all, it underlines that policymakers need to account for their countries' dynamic economic structure to ensure the long-term success of adaptation and risk-management strategies.

Box 4 Impacts of climate variability and change on poverty – Nigerian case study

Prof. Eric C. Eboh, Dr. Nathaniel E. Urama, Dr. Onyekwuru Anthony, and Yuni Denis Nfor, University of Nigeria-Nsukka

After rebasing its GDP, Nigeria overtook South Africa to become Africa's largest economy in 2014 and the world's twentieth largest economy with an average growth rate of 7.4 per cent (World Bank, 2017). This increase in GDP notwithstanding, the proportion of Nigerians living in poverty has been increasing over the years. The World Bank reports that over 60 per cent of the country's population were living below the poverty line of \$1.25 per day in 2014 and that Nigeria is one of the five countries having the largest number of poor people in the world. This poverty has persisted despite the oil boom and all the poverty-eradication programmes in the country. To improve the effects of poverty-eradication programmes and reduce poverty in developing countries, in a paper presented at the Eighth Conference of Parties to the United Nations Framework Convention on Climate Change in New Delhi, 2002, the African Development Bank Group suggested integrating climate change and adaptation in poverty-eradication programmes. This necessitates improved assessments of the impact of climate change and extreme climate events on poverty and effectiveness of poverty-eradication programmes across the globe.

With a very high proportion of the government revenue from oil, macroeconomic variables are not very responsive to climate variability (Abidoye & Odusola, 2015), smoothing out the economic impact of climate variability and extreme climate events. Consequently, climate change, mitigation and adaptation have not been given due attention in spite of potential consequences for poorer strata of the population. Indeed, the poverty-alleviation programmes in Nigeria have been implemented without regard for the impact of climate change and extreme climate events, like the floods of 2012, on the poor population. This case study therefore aims at assessing the impact of the 2012 flood on poverty that occurred in Nigeria and affected about 2,769,415 individuals (CRED, 2017). Specifically, the case study investigates whether there is a significant difference in poverty status of households before and after the 2012 flood, and whether the poverty effect of the flood is dependent on certain socioeconomic characteristics of households.

The analysis focuses on the impact of a one-time extreme wet event, here a flood, using survey data from two periods, separated by the studied extreme wet event. The methodology consists of a comparative analysis to observe whether the 2012 flood had a significant impact on household poverty in the affected states. The study employs a panel analysis of covariance (PANCOVA) model, which involves the use of dummy variables to capture the pre- and post-value of household per capita expenditure. The analysis also assesses the relative weight of the impact on households depending on the percentage of their income earned from agriculture, and the gender of the household head, using the Nigerian General Household Survey data of 2011 and 2013, both with a sample size of 4,991.

On average, only 28.7 per cent of the surveyed households live in urban areas, and male- and female-headed households are almost equally distributed. In 2011, about 40 per cent of the surveyed population had access to credit, while in 2013 this increased to 45 per cent. The results show a decrease in the average percentage of employed household members from 40 per cent in 2011 to 35 per cent in 2013, and about half of these were employed full-time in the agricultural sector. In terms of formal education, about 40 per cent of the sample had no formal education during both surveys. An average of 16.6 per cent had primary and 12.6 per cent secondary

education as their highest level of education, and about 30 per cent of the sample had a certified higher degree.

Results of the comparative analysis of the households affected and not affected by the 2012 flooding event show that:

- The flood reduced the average per capita income of the affected households by ₦3,526, increasing their probability of falling into poverty, if they were not already in poverty, or increasing the poverty gap if they were already in poverty.
- In the flood-affected states, households that are heavily dependent on agriculture have a higher probability of being poor as compared to those with smaller percentage of their source of livelihood from agriculture.
- The consequence of the flood for poverty was more severe on the population with a high percentage of income from agriculture.
- The poverty impact of the flood was higher in female-headed households than in male-headed households.

In conclusion, the study finds that the severe flood that occurred in Nigeria in 2012 had a significant negative impact on the affected households' per capita income, increased the probability of falling into poverty and increased the poverty gap in the country. The results also show that the poverty impact of such an extreme climate event is not uniform across the affected individuals, but that it depends significantly on their socio-economic characteristics, hitting households harder if livelihoods depend on agriculture and if they are female-headed.

the incidence and severity of poverty and the poverty gap are still increasing, despite the high growth rate and series of poverty-alleviation/eradication programmes in the country for years, is a source of concern for the development and stability of the country. From the findings of this research and other reviewed literature, two main recommendations can be made:

- Climate change and adaptation strategies should be integrated into the poverty-alleviation/eradication programmes in the country.
- Climate adaptation intervention should be targeted more at the poor who draw a large proportion of their income from agriculture and at female-headed households.

5. Long-term adaptation cost and benefit estimates

5.1 AD-AFRICA model

While it is important to understand the expected impacts of climate change in Africa, assessed in chapters 2 and 3, it is equally important to understand the role adaptation can play in reducing these impacts and to explore the resulting adaptation costs. Appropriate use of adaptation can reduce impacts substantially. Estimating adaptation costs and benefits can help plan for early and future adaptation and result in sound planning and use of adaptation options, and hence deliver higher benefits for lower costs (and thus significantly lower total damage costs). Adaptation literature generally focuses on the costs, while adaptation benefits are rarely explicitly estimated on a large scale. Adaptation benefits are defined here as the amount of damage reduced through adaptation, i.e. gross damage minus residual damage. Adaptation benefits are extremely important as they represent the potential reduction in damage that can be achieved, and thus the level of effectiveness and efficiency. In this framework, adaptation is only undertaken when benefits outweigh costs.

Adaptation costs have been estimated in literature earlier (e.g. Raworth, 2007; UNDP, 2007; UNFCCC, 2007; World Bank, 2009), and have focused on the relative short term, i.e. to 2030, consistent with providing information on the international negotiations around international climate finance. These short-term estimates of adaptation costs provide key information but, to combat climate change effectively, an understanding of long-term (next 100 years) adaptation options and costs is important. In particular, for planned proactive adaptation investments, this understanding is needed well in advance of the period when such investments will actually be needed, given the long lead time of resource mobilization and national and international policy processes. In addition, many adaptation measures, and hence investments, need to be implemented in advance and adaptation costs are expected to increase over time, so reliance on short-term estimates may lead to an underestimation of expected costs and investments in the longer term.

The AD-AFRICA model consists of five African regions (Eastern, Western, Southern, Northern, Central) and seven climate-change-impact sectors (agriculture, health including mortality and morbidity, tourism, fisheries, coastal, water and road infrastructure). The regional aggregation is based on the African Development Bank's proposed regions as shown in Table 3.1. The model is calibrated to replicate the regional economic growth projections for the SSP2, middle-of-the-road scenario (Dellink et al., 2015). Climate-change impacts per region and impact sector are then estimated based on impact literature. These impacts are a function of global temperature change, regional temperature change or global sea level rise. Though precipitation plays an important role in climate-change impacts, it is not used here as an input into the damage function as most estimates show damages for a certain temperature and precipitation level making it impossible to distinguish between the temperature and precipitation effects. Hence the global temperature in our model also includes precipitation effects. In the framework of this report, climate change will create initial impacts (gross damage), which can be reduced through the use of adaptation resulting in actual damage felt (residual damage). The differences between gross damage and residual damage are the benefits of adaptation. Figure 18 gives an overview of the impact sectors included in the model. Annex 1 provides a more detailed description of

the model. Below is a brief description of the impacts and adaptation considered in the model.

Table 2 Regional aggregation in the AD-AFRICA model

Region	Countries
Northern	Algeria, Egypt, Libya, Morocco, Tunisia and Mauritania
Western	Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo
Eastern	Burundi, Comoros, Djibouti, Eritrea, Ethiopia, Kenya, Rwanda, Seychelles, Somalia, Sudan, South Sudan, Uganda and United Republic of Tanzania
Central	Cameroon, Central African Republic, Chad, Congo, Democratic Republic of the Congo, Equatorial Guinea, Gabon and Madagascar
Southern	Angola, Botswana, Lesotho, Malawi, Mauritius, Mozambique, Namibia, Sao Tome and Principe, South Africa, Swaziland, Zambia and Zimbabwe

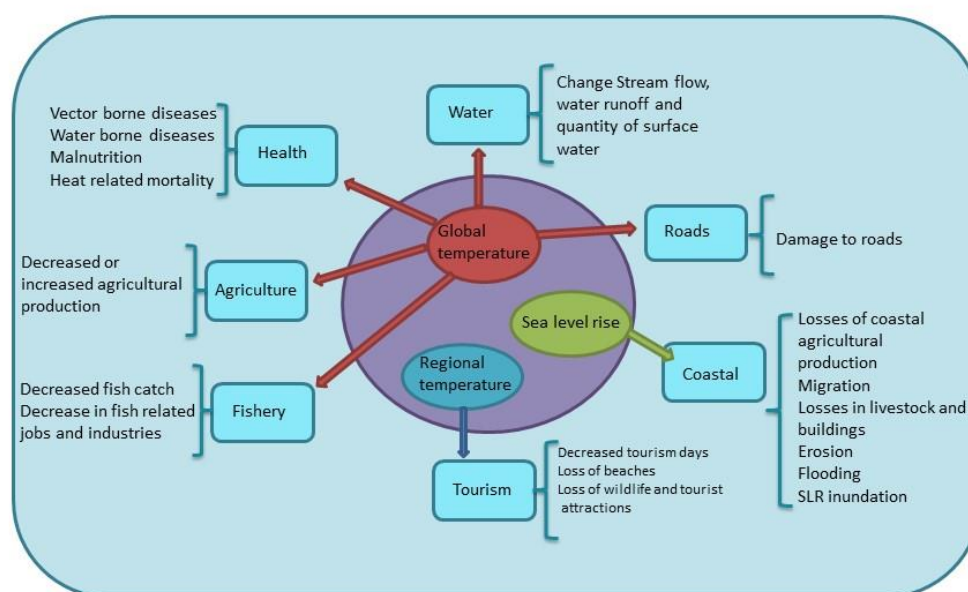


Figure 18 Overview of the impact module in the AD-AFRICA model

5.2 Impacts and adaptation

Climate impacts on GDP are estimated here based on impact-assessment literature from the different impact sectors.

Adaptation options are modelled based on the adaptation costs and benefit literature. Where this is lacking, cautious estimates (underestimating adaptation benefits rather than overestimating) are made based on the impact estimates. However, it should be noted that these estimates are based on technical adaptation options, which generally overestimate benefits and underestimate costs. This analysis distinguishes between two forms of adaptation in each sector, namely flow adaptation and stock adaptation. This distinction has been made to enable a more accurate description of the costs and benefits of different forms of adaptation and hence the total adaptation costs.

Box 5 Limitations of Integrated Assessment Model (IAM) approaches for impact assessment

This methodology has a number of limitations, which should be kept in mind when interpreting the results.

Firstly, the damage assessments are not comprehensive. Since this assessment can be seen as a meta-analysis of the broader scientific literature on impacts and damages, it is by definition limited to those impacts and sectors for which sufficient, reasonably conclusive data are available from the existing scientific literature. Hence, a limited number of sectors are assessed, where many other impact sectors have not been included, such as extreme events, ecosystems, forests, conflict, energy etc. Even for the sectors that are studied here, not all impacts within the sectors are included. This is discussed in more detail for each sector.

Secondly, this assessment generally only includes direct impacts and not secondary impacts on other sectors. Many sectors (e.g. agriculture) will create impacts throughout the economy, for example where other sectors in the economy use agricultural inputs, or when other sectors' produce is used as inputs into agriculture. Other secondary economic effects could arise through changes in consumption. These secondary effects could be as large as or even larger than the direct impacts.

Thirdly, the assessment does not consider the longer-term effects of these impacts on a region's development, poverty-eradication efforts and income. Damages are treated as one-time GDP reduction events which will have impacts on the future economy through changes in investments. However, these damages could decrease not only GDP, but productivity, so that future GDP and GDP growth paths are affected as well. Including such effects could increase or decrease the damage estimates.

Finally, this assessment does not consider distributional effects of impacts both geographically and across incomes. Impacts are presented as a percentage of regional GDP; this camouflages the much larger impacts at the national or local level. For example, impacts in the coastal sector may seem small on a regional scale, but for coastal areas these impacts may be disastrous. Moreover, the poor are often affected more than others, and the effects can be tremendous in terms of their income.

Flow adaptation describes adaptation measures that can be taken in reaction to climate change or climate change stimuli. This form of adaptation comes at a relatively low cost and is generally undertaken by individual households and the private sector and therefore is also referred to as reactive or private adaptation (though flow adaptation is not by definition reactive or private). In the rest of this chapter the term "reactive adaptation" will be used for convenience. Examples of this form of adaptation are the use of air conditioning and changing crop-planting times. When flow adaptation decisions are made, they tend to be made on the basis of immediate economic costs and benefits. The costs and benefits fall within a relatively small period of time (in this

model five years). The benefits of reactive adaptation are only felt for a limited time period (in this model, reactive adaptation only provides protection from climate change damages for five years).

Stock adaptation, on the other hand, refers to adaptation measures that require investments in advance of the effects of climate change being felt. Stock adaptation is generally considered to be anticipatory adaptation. In the rest of this chapter this form of adaptation will be referred to as anticipatory. Anticipatory adaptation is modelled as investments in building adaptation capital. The benefits of this capital are not felt immediately, but create a stream of benefits in the future. Anticipatory adaptation investments made today will create adaptation capital in the next decade. The adaptation capital reduces damage as long as it is still in place. The adaptation capital depreciates over time, i.e. it does not last forever and will need to be replenished. This form of adaptation usually requires large-scale investments by Governments and therefore is often a form of public adaptation (although there is now a move toward iterative climate-risk management, with information, learning and option values, flexibility and robustness). Examples of this form of adaptation are research and development into new crop types or the development of a plan for sea-level rise that might include the construction of a dam. When decision-makers decide how much to invest in the building of adaptation capital, they need to weigh the costs incurred against a stream of future benefits. The investment costs are incurred now whereas the actual benefits in the form of reduced damage are expected in the future. As adaptation capital reduces damages for several decades, the decision-maker will need to calculate and discount the future benefits and weigh these against the investment cost.

In summary, adaptation costs in this model consist of anticipatory adaptation investments and reactive adaptation costs.

5.3 Future estimates

5.3.1 Impact sectors

This section briefly discusses the impact sectors and adaptation options in the AD-AFRICA model. It also presents the estimated gross damage, residual damage, anticipatory adaptation costs (adaptation investments) and reactive adaptation costs for the different regions and impact sectors in the year 2050 for the above 4°C world scenario as a percentage of GDP.

Box 6 Difference in damage estimates between the AD-AFRICA model and the econometric analysis

The AD-AFRICA model-based approach to estimating damage is very different from the econometric approach used in chapter 3, where the different methodologies can complement each other and create a broader understanding of the range of future climate-change impacts.

The approach of chapter 3 assesses the direct relationship between climate stimuli and GDP growth using an econometric approach, which gives a greater understanding of expected damage in the next decades. This is indeed the purpose of such an analysis: to form a clearer idea of the potential magnitude of climate-change

impacts that have not yet been assessed (such as various impact sectors not yet quantified) or understood (such as growth impacts) at a process level. This assessment of damage could be expected to be higher, as it captures elements not quantified, or quantifiable, in formulated models, such as Integrated Assessment Models (IAMs).

In AD-AFRICA, the impacts and adaptation costs and benefits for several impact sectors are estimated and aggregated to estimate total damages and adaptation costs in the long term. Here damages are considered as one-time decreases in GDP. Here the dynamics of economic growth are specified directly using a neo-classical growth model, where impacts affect long-term growth through potential decreases in capital investments due to impacts and/or adaptation investments. The purpose of an IAM is threefold: firstly, to create a better understanding of where in the economy future impacts will arise by using an impact sector approach; secondly, to investigate the dynamics and long-term consequences of climate change; and finally, to understand the role adaptation policies can play in reducing damage and at what cost.

AD-AFRICA naturally does not include all possible impacts, nor does it fully consider the spillover effects from one sector to another and the long-term growth impacts, which can be captured in the econometric analysis of chapter 2. The AD-AFRICA approach would result in lower impacts as compared to using an econometric analysis such as in chapter 2, as indeed we see here. This does not mean that the results of AD-AFRICA and the econometric analysis contradict each other. When considering the methodological differences, the differences in results can be explained; the key challenge is to derive robust messages from each approach, given the respective inherent limitations.

The main issue is interpreting both sets of results together. For now, we can tentatively conclude that future climate-change damages and adaptation costs are likely to be higher than estimated by the AD-AFRICA model.

Agriculture

A large part of the agriculture sector in African regions is still characterized by subsistence farming and rain-fed crops, which makes it particularly sensitive to climate change. Increases in temperature and precipitation variability are expected to impact crop yields both positively and negatively through drought, flooding, carbon fertilization, growing season length and water sources (Adhikari et al., 2015; Calzadilla et al., 2013). We estimate changes in yields for the most common crops including maize, rice, sorghum, wheat, cassava, yam and sugarcane. Literature used to assess the percentage change in crop yields include Fischer (2009); Knox et al. (2012); Ringler et al. (2010); Tatsumi et al. (2011). This is converted into impacts as a percentage of GDP based on the agricultural production per crop type. This does not include the impacts of trade, which can offset these impacts through the improved comparative advantage of the African agricultural sector, given that Africa can benefit from increased agricultural process through trade. When estimating future impacts, we need to consider that, as regions develop, the relative importance of the agricultural sector in terms of total economic production will decrease. The assessment of the agriculture sector (and the

source literature) takes into account the positive effects on crop production of CO₂ fertilization and the positive and negative effects of changes in temperature and precipitation. Not accounted for are changes in pests, decreases in nutritional value related to CO₂ fertilization (Porter et al., 2014), the effects of climate extremes on harvest failure and permanent shifts in crop suitability areas. The effects of changes in crop yields are expressed in terms of percentage of total regional GDP, which therefore does not reflect effects of changes in crop yields on rural development, employment, education and health. However, some of the effects on health are expressed in the assessment of mortality and morbidity due to undernourishment within this model.

To capture the effects of development on the agriculture sector, agriculture production over time is estimated using an elasticity of -0.31 (Tol, 2002). The more important agricultural production in a region, the larger the impacts of agriculture in terms of percentage of GDP. The share of agricultural production in total production is low in Southern Africa at 4.3 per cent in 2010, declining to 3.3 per cent in 2050. Northern Africa also has relatively low levels of 9.9 per cent in 2010, declining to 6.9 per cent in 2050. Central Africa's agricultural production represents 18.4 per cent of total production in 2010, declining to 11.7 per cent in 2050. Eastern and Western Africa have similar shares of 29.6 per cent and 30.5 per cent respectively in 2010 and 18.7 per cent and 18.3 per cent respectively in 2050. We have chosen not to include agricultural impacts for North Africa as the data sources had conflicting conclusions, where some indicated an increase in yield and others a decrease.

West Africa has by far the largest agricultural impacts (in terms of percentage of total regional GDP) with gross damage of 1.9 per cent of GDP in 2050. East Africa follows with 1 per cent and Southern Africa with 0.4 per cent. Central Africa has the lowest impacts with 0.07 per cent. Impacts in the agricultural sector are expected to significantly increase as temperature rises (Thornton et al., 2011).

Several studies estimate the impacts of adaptation on global agricultural yield. Reilly & Schimmelpfennig (1999) estimate that adaptation can decrease impacts on yield by 30 per cent; Fischer, (2009) estimates this at 35 per cent, as do Tan & Shibasaki (2003). Reflecting the risk assessment for agriculture in Africa from AR5 WGII, this assessment assumes that adaptation is more effective in reducing damage at low temperatures and becomes virtually ineffective at 4°C temperature increase. Adaptation levels (percentage of gross damage reduced) are on average 50 per cent at a 1°C temperature increase, 30 per cent at a 2°C increase and 7 per cent at a 4°C increase. Adaptation options include changing of planting times, changing of crop types, increased irrigation, investments in irrigation infrastructure and research and development of heat-resistant crop types. Reactive adaptation can significantly decrease agricultural damages at a low cost. However, some adaptation capital is needed to ensure that reactive adaptation is used to its full potential, such as knowledge of potential expected climate change effects. Some irrigation infrastructure will be needed to further reduce damages. This leads to low reactive adaptation costs, but significant anticipatory adaptation investments.

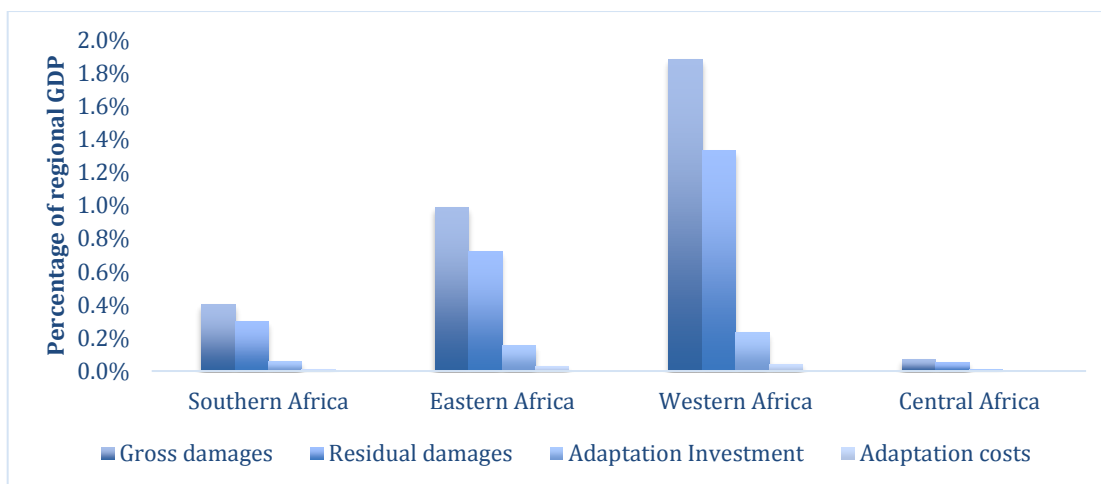


Figure 19 Gross damages, residual damages and anticipatory adaptation investments and reactive adaptation costs in 2050 for each region in the agriculture sector for the above 4°C world mitigation path as a percentage of regional GDP.

Box 7 Adaptation in the agricultural sector of Northern Africa: Morocco case study

Riad Balaghi, National Institute for Agronomic Research of Morocco

For the Northern Africa region, the broader literature is highly uncertain in terms of climate change impacts and adaptation in the agricultural sector. As explained, AD-AFRICA does not provide estimates for this sector for Northern Africa. However, more detailed studies at the national level can help fill this gap, which is done here for Morocco.

In Morocco, agriculture is an important sector for the national economy, contributing 15 to 20 per cent to national GDP, depending on the years. Agriculture (including fishing) is the largest sector in terms of employment (38 per cent of national employment and 75 per cent of employment in rural areas). The sector underpins Morocco's food security and sustainable development. Agricultural areas cover 8.7 million hectares out of Morocco's total of 71 million hectares. As in most Mediterranean countries, the cereal system (i.e. cereals/livestock/olive tree) is predominant, with cereals covering 65 per cent of agricultural lands. Ten per cent of agricultural land is fallow. Olive orchards cover 680.000 hectares, i.e. 55 per cent of fruit tree areas. Crops form the major contribution to agricultural added value, on average 60 per cent over the 1980-2002 period, while livestock contributes 31 per cent. During dry seasons, the relative contribution of livestock to GDP increases, due to its important role as a household savings account.

The Green Morocco Plan, the new agricultural strategy of Morocco towards 2020, aims at increasing growth, reducing poverty, ensuring long-term sustainability of the agricultural sector and consolidating its integration into national and international markets. This Plan includes significant socioeconomic benefits in terms of value added, investment, job creation, and improving farmers' incomes. However, as a consequence of climate change and growing population, agriculture will be challenged due to decreasing water availability, increasing temperatures and increasing food needs. One seventh of the Green Morocco Plan focuses on the implementation of projects, which improve the resilience of agriculture to climate change and which preserve land and biodiversity, demonstrating that climate change is a vital concern.

The overall objective of the Moroccan case study is to develop a deeper understanding of the costs and benefits of adaptation in the agricultural sector and its potential implications for economic development in the country. The analysis consists of the following elements:

- Review of existing studies or analyses of past agricultural and precipitation/temperature data to infer consequences of climate change;
- Identification and selection of adaptation options using results from existing studies

Projected climate

Morocco is a hotspot of climate change according to the Intergovernmental Panel on Climate Change (IPCC, 2014b). According to recent detailed studies on climate change in Morocco, decreasing rainfall

will affect the whole country towards the end of the century, as demonstrated by Figure 9. Rainfall will decrease particularly during fall and spring, when rainfall peaks usually occur. Simultaneously, average annual temperature is expected to increase from 1.1 to 3.5°C around 2060 and 1.4 to 5.6°C around 2090. Consequently, evapotranspiration (water demand from crops) will increase by 20 per cent around 2050 and by 40 per cent around 2080, with the exception of the Saharan region.

Impacts of climate change on agriculture

The impacts of climate change on agriculture have been assessed in a comprehensive study in 2009, which was launched by the Ministry of Agriculture and Marine Fisheries of Morocco, in collaboration with the Food and Agriculture Organization of the United Nations (FAO), the National Institute for Agronomic Research and the meteorological administration. Because of climate change, since most agricultural lands are rain-fed, yields of major crops are expected to decrease in the long term, in parallel with increasing year-to-year variability in crop production. In marginal areas, agricultural drought will affect the livelihoods of rural communities. The reduction in availability of surface water and aquifer recharge will undermine the prospects for irrigated agriculture. Lower and more variable yields will result in greater dependence on imported food, making Morocco more vulnerable to international food price volatility. The assessment of the economic impact of climate change on agriculture was conducted by the World Institute for Research on Development Economics, based on the above-mentioned study. GDP is estimated to decrease by between 0.4 and 3.1 per cent by 2050, according to climate scenarios (this report estimates median losses between 10.3 and 14.7 per cent in GDP per capita by 2050 in the low- and high-warming scenarios), if no measures are taken to adapt to climate change. However, if fully implemented, the Green Morocco could deflect the negative effects of climate change.

Adaptation to climate change in agriculture

Since the launching of a programme for irrigating 1 million hectares in 1967, many climate change adaptation measures in agriculture undertaken by the Department of Agriculture could hold valuable lessons for future policy development both in Morocco and in other countries:

- **Adaptation measures to climate change in agriculture, supported in the framework of “The Project on Integration of Climate Change in the implementation of the Green Morocco Plan” (PICCPMV).** These measures include conservation agriculture, rainwater harvesting techniques, supplemental irrigation, use of selected seeds, etc.
- **The promotion of soil and biodiversity conservation measures in ongoing development projects of the Green Morocco Plan, in the framework of “The Solidarity and Integrated Agriculture Project in Morocco” (ASIMA).** These measures aim at moderating land and environmental degradation that may reduce the production capacity of marginal lands, further increasing poverty in rural areas. The project can serve as a source of experience for the improvement of livelihoods in desert ecosystems.
- **Broad dissemination of innovative technologies and policy measures for adaptation to climate change in agriculture in Morocco and Tunisia, in the framework of the project “Adaptation to Agriculture to Climate Change in the Maghreb”.** Key measures include agricultural insurance, conservation agriculture, the use of drought- and disease-resistant crop varieties, and farmers’ training.
- **The cultivation of fruit trees instead of annual crops, in mountain areas.** This was done under the conversion programme of cereal areas in orchards, which consists in planting fruit trees on about 1 million hectares by 2020 in Morocco. The plantations are designed to improve farmers’ income and reduce land degradation, through optimal fertilization, rainwater harvesting, supplemental irrigation and preservation of soils against erosion. The programme has been highlighted as one of the main contributors to improving livelihood in highland areas, along with its significant impact on reducing land degradation. It is also the largest contributor to sequestration of greenhouse gases.
- **The conversion of surface irrigation into drip irrigation over large areas, to save irrigation water.** This was done in the framework of “The National Irrigation Water-Saving Programme”, which targets the conversion of about 550,000 hectares to drip irrigation by 2020.
- **Securing market supply in cereal crops for certified seeds (soft wheat, durum wheat and barley) and improving their level of usage by farmers.** This is done in the framework of “The procurement programme to secure the use of certified cereal seeds”, which aims at improving crop yields and seed quality. Selected seeds of improved varieties are the main driver of technology transfer, especially in developing countries where access to the technology is unaffordable for most farmers.

- **Date palm planting and renovation in oases for improving living standards of the poor and reducing rural flight of young people.** In Morocco, the “National Programme for Date Palm Development” aims at planting 3 million trees by 2020 and intensification of existing palm plantations on 48,000 hectares, and the creation of new modern plantations on 17,000 hectares, in areas where irrigation water is available.
- **The multi-risk climate insurance for cereals and pulses, as a tool for reducing the effect of climate hazards especially in dry areas.** The Ministry of Agriculture of Morocco aims at promoting the index-based agricultural drought insurance for small farmers, especially for cereals (wheat, durum wheat and barley), in order to improve risk coverage through better yield estimates, and to accelerate payments of claims.

Conclusion and recommendation

Morocco has designed a promising strategy for the development of the agricultural sector, in order to increase income, preserve the environment and adapt to climate change. Already existing actions for adaptation are successfully implemented at the national level and some of them are innovative. However, there is still a need for investments, knowledge and technology development and transfer. Morocco could benefit from its “advanced status” with the European Union, to raise funds, search for collaboration, and promote the environmental quality and traceability of local production, imports and exports. Also, there is a need for strengthening current North-South and South-South collaborative schemes.

Coastal impacts

Global warming is projected to increase the melting of permafrost and sea ice (Antarctic and Greenland) leading to a rise in sea levels globally and along African coasts. Consequently, this will cause displacement of people, impairment of infrastructure, flooding, loss of livelihood, destruction of coastal fisheries and aquaculture farming, loss of beaches, reduced resilience of corals, loss of crops and livestock, intrusion of salt water, altered water run-off, increases in storm surges and larger waves (Dasgupta et al., 2011; Hinkel et al., 2012).

The calibration of coastal impacts in the AD-AFRICA model relies on the findings of Hinkel et al. (2012), who evaluate the impact of global mean sea-level rise in 2100 as a result of climate change for African coastal countries using the DIVA model²⁰ for four different scenarios. In this study, impacts are evaluated by looking at the differences between sea-level rise scenario and no sea-level rise scenario. Investments needed, given the current condition, are excluded from the analysis, which means that protection needed for current climatic conditions is not included in the calculation of adaptation costs. In Hinkel et al. (2012), damages without (further) sea-level rise are often very high in most cases, about half the size of the total damages in the extreme scenario of 126 cm of sea-level rise in 2100, implying significant coastal impact in Africa even with the current climate.

This assessment considers the cost of sea surge floods, coastal river floods, land loss through flooding and submergence, salinization, and forced migration due to frequent flooding. It does not consider damage to ecosystems or willingness to pay to avoid losses of beaches and coastal land. The RICE model (W.D. Nordhaus, 2010; W.D. Nordhaus, 2010) evaluates damages based on a willingness-to-pay (WTP) approach, resulting in damages 15 to 100 times higher in Africa (Hof 2014). Accordingly, the results reported in Schaeffer et al. (2014) and Schaeffer, Baarsch, Adams, De Bruin, et al. (2013) based on the AD-RICE model also have higher coastal impacts. The differences between coastal impacts in the DIVA model and in the RICE model (and

²⁰ <http://www.diva-model.net/>.

PAGE model) are discussed in Hof (2014), where the DIVA estimates are considered to be more applicable.

In this assessment, gross damages consist mostly of damage due to salinity intrusion in 2050. In 2100, gross damages due to sea floods predominate, followed by salinity intrusion, migration and river floods. The highest contributor to residual damages in both 2050 and 2100 is salinity intrusion, where most residual damages are caused by salinity intrusion in 2050 and about 60 per cent in 2100. Sea floods and, to a far lesser degree, migration contribute to residual damages in 2100. Adaptation to gross damages due to river floods completely eradicates damages, resulting in no residual damages due to river floods.

Adaptation estimates are also based on the DIVA results, where adaptation costs and benefits are directly reported. Adaptation costs are high in the coastal sector and consist solely of beforehand investments (anticipatory adaptation). Adaptation investments are higher in earlier years, as adaptation capital is built up. Adaptation options include beach nourishment, sea-wall expansion and sea-wall maintenance.

Gross damages due to sea-level rise are relatively small as a percentage of regional GDP in 2050, with 0.012 per cent in Southern Africa, 0.011 per cent in Northern Africa, 0.002 per cent in Eastern Africa and Western Africa and 0.006 per cent in Central Africa. It should be noted that looking at impacts as a percentage of regional GDP neglects the larger impacts in certain countries, which can be more than ten times larger in terms of the country's GDP, e.g. gross damages in 2100 in Mozambique are 0.15 per cent of GDP, in Guinea-Bissau 0.17 per cent, in Egypt 0.17 per cent and in the Gambia 0.23 per cent. In the case of certain cities or regions within countries, these impacts are even larger in terms of local production. Impacts on the coastal sector are expected to increase linearly with sea-level rise, roughly doubling by 2100 as compared to 2050.

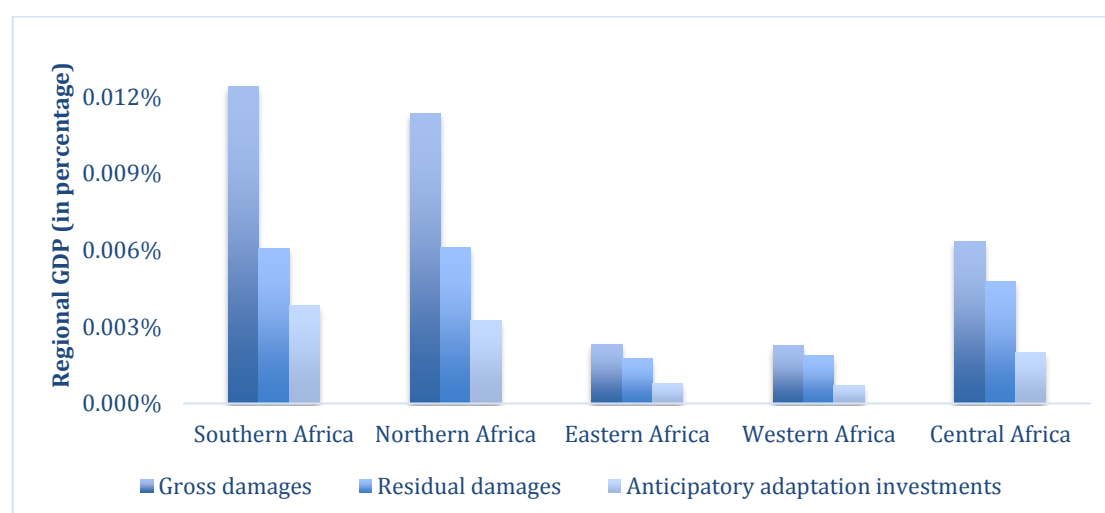


Figure 20 Gross damages, residual damages and anticipatory adaptation investments in 2050 for each region in the coastal sector for the above 4°C world mitigation path as a percentage of regional GDP.

Fishery

Changes in climate are projected to affect fishery ecosystems through coral reef bleaching, intrusion of saline water into freshwater fisheries and high evaporation in

catchment areas, resulting in altered distribution and quantity of fishery resources. Moreover, extreme flooding events and large storms are expected to impose difficulties on fishing processes and damage fishing infrastructure. Climate-change impacts on fishery can also be assessed through their indirect effects on food security, fish-related jobs and industries (Allison et al., 2009; Lam et al., 2012). This assessment estimates the economic impact, which is calculated by estimating the impact on the landed value of fisheries and multiplied by the national fishing output multipliers. This captures, albeit in a static manner, the relationship between fishery and other sectors of the economy. Effects on food security are captured, at least partly, through malnutrition impacts in the morbidity and mortality sectors.

This assessment projects climate impacts on fisheries for West and Northern Africa only. As assessed by Cheung et al. (2010), future catching potential and distribution of fisheries at the coasts of these two regions are vulnerable to climate change, whereas impacts in terms of fish catch in other regions are expected to be negligible. This assessment uses estimated impacts from Lam et al. (2012) who estimate the response of total fishery sectors due to climate change for Western Africa and extrapolate the same impacts on Northern Africa, as impacts in Western and Northern Africa are expected to be similar (Cheung et al., 2010). Lam et al. (2012) evaluate the effects of climate change on future potential catch and its multiplier effect on other sectors of the economy. Fishery production as a percentage of total production in 2010 in Western Africa is 0.6 per cent and 0.2 per cent in Northern Africa but is projected to decrease as these regions develop. Impacts in 2050 are expected to be 0.013 per cent of GDP in Western Africa and 0.04 per cent in Northern Africa.

Adaptation options in the fishery sector include improved fishing infrastructure and technologies, the introduction of new species, aquaculture, controlled fishing (e.g. use of permits) and alternative livelihoods. Adaptation capacity in fishery, in particular in Western Africa, is quite low.

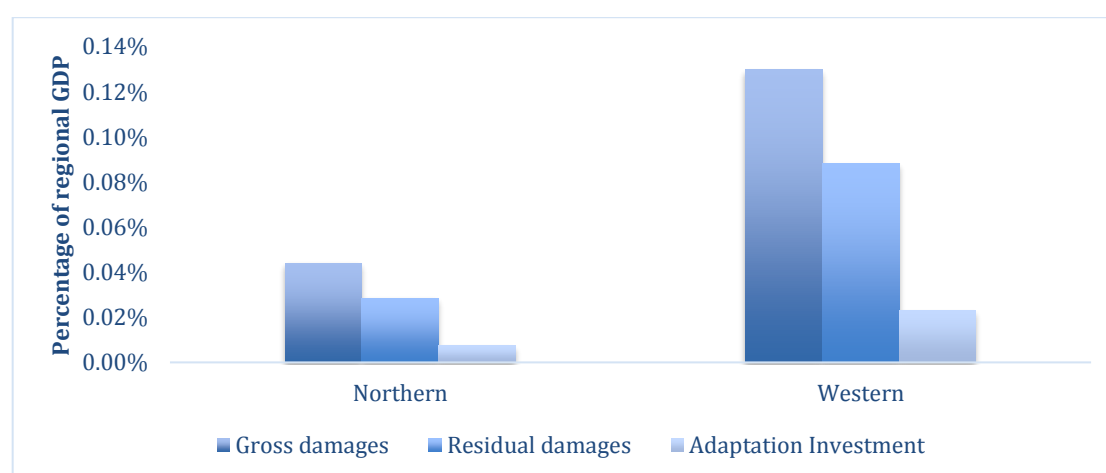


Figure 21 Gross damages, residual damages and anticipatory adaptation investments and reactive adaptation costs in 2050 for each region in the fishery sector for the above 4°C world mitigation path as a percentage of regional GDP.

Health: mortality and morbidity

Human health impacts of climate change are estimated through its impact on malaria, undernourishment, diarrhoea and heat-related mortality. Other health impacts not assessed here include the increase of such diseases as cholera, schistosomiasis, meningitis, hantavirus, and leishmaniasis; the analysis also excludes potential benefits of climate change (impacts of fewer cold extremes for example). The interactions of diseases with the prevalence of HIV is another potential threat that could be considered (AR5). Health impacts are divided into mortality impacts and morbidity impacts.

Figures relating to additional deaths due to climate change (mortality) and years of healthy life lost due to disability (YLDs) (morbidity) are taken from Hales et al. (2014). Following Tol (2002), YLD is valued at income per capita, while changes in the risk of mortality are valued at 200 times income per capita.²¹ Socioeconomic development will lessen the occurrence and severity of diseases, undernourishment and heat-related deaths. An elasticity to income per capita of -0.85 is assumed following Tol (2008), where vector-borne diseases and per capita income are inversely related. Mortality impacts (both in terms of number of deaths and value of deaths) are smallest in Southern Africa with gross damages of 0.1 per cent in 2050. Northern Africa has 0.5 per cent gross damages in 2050. Western Africa has 0.8 per cent and Eastern Africa and Central Africa have the highest impacts at 1.8 per cent of GDP. The relative importance of different mortalities differs across the regions. In Southern Africa and Middle Africa, undernourishment dominates, in Northern Africa heat-related deaths, in East both Malaria and undernourishment are the main causes of health-related deaths. In Western Africa, undernourishment and diarrhoea dominate. Morbidity impacts are lower at between 0.02 per cent of GDP in 2050 in Southern Africa and 0.6 per cent in East Africa.

Adaptation in the health sector includes a combination of preventively-based healthcare adaptation options such as the use of mosquito nets, improved sanitation, prolonged breastfeeding, use of medication and air-conditioning (Ebi, 2008), as well as anticipatory adaptation such as increased health infrastructure (hospitals and clinics) and knowledge-building. Adaptation has a large potential to decrease impacts in this sector at a relatively low cost, following the risk assessment for infectious diseases in Africa from the last IPCC AR5 report (IPCC, 2014b).

²¹ Though this means that risk of death is valued differently in monetary terms, in utility terms (which is a function of income per capita) this results in a more equal valuation. As the model maximizes utility, this means that the decision variables will be less biased towards valuing a life more highly in a richer country.

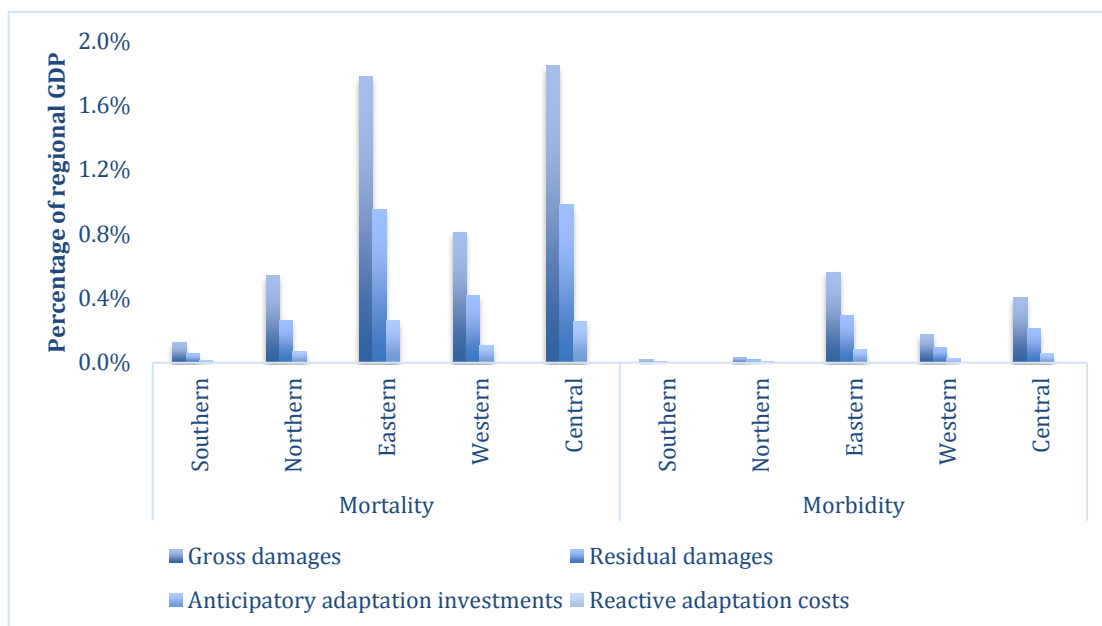


Figure 22 Gross damages, residual damages and anticipatory adaptation investments and reactive adaptation costs in 2050 for each region in the health sector (mortality and morbidity) for the above 4°C world mitigation path as a percentage of regional GDP.

Road infrastructure

High temperature, sea-level rise and increases in precipitation due to climate change are projected to influence the functioning and life span of road networks. How climate change will impact road infrastructure largely depends on the design, material and type of road network and impacts will vary for paved, gravel or dirt roads. Most countries in Africa have a high share of unpaved and below-standard existing paved road networks, which, coupled with low adaptive capacity, poses a higher climate-change impact threat to road infrastructure in Africa as compared to other regions of the world (Chinowsky, Hayles et al., 2011; Chinowsky, Schweikert et al., 2011; Twerefou et al., 2015).

High temperature affects the texture and hardness of asphalt of the road surface and makes it more vulnerable to cracking. Increased and heavy precipitation generates and widens potholes on unpaved roads through increased erosion. Flooding due to the sea-level rise impacts the road infrastructure in different ways, including blocking road networks, eroding away gravel, destroying bridges and blocking culverts (Galbraith et al., 2005; Twerefou et al., 2015). This assessment estimates the impacts on road infrastructure based on Chinowsky, Hayles et al. (2011), where impacts are estimated through climate change stimuli (temperature and precipitation) impacts on road lifespan with and without adaptation. This analysis does not consider impacts of storms, extreme events or flooding. Impacts on potential new road infrastructure, which is critically needed and indeed often under construction or planned, are not considered. Gross damages in road infrastructure are similar across regions ranging in 2050 from 0.011 per cent of GDP in Southern Africa to 0.016 per cent in Central Africa.

There are a number of adaptation options to deal with the effects of climate change on road infrastructure. These include: using asphalt mix and permeable road surfaces in road construction as measures for tolerating high temperature and heavy rainfall, enhancing drainage systems and upgrading of gravel and dirt road networks. Adapting

roads to future climate change stressors during regular maintenance and expansion can greatly decrease damage at a low cost.

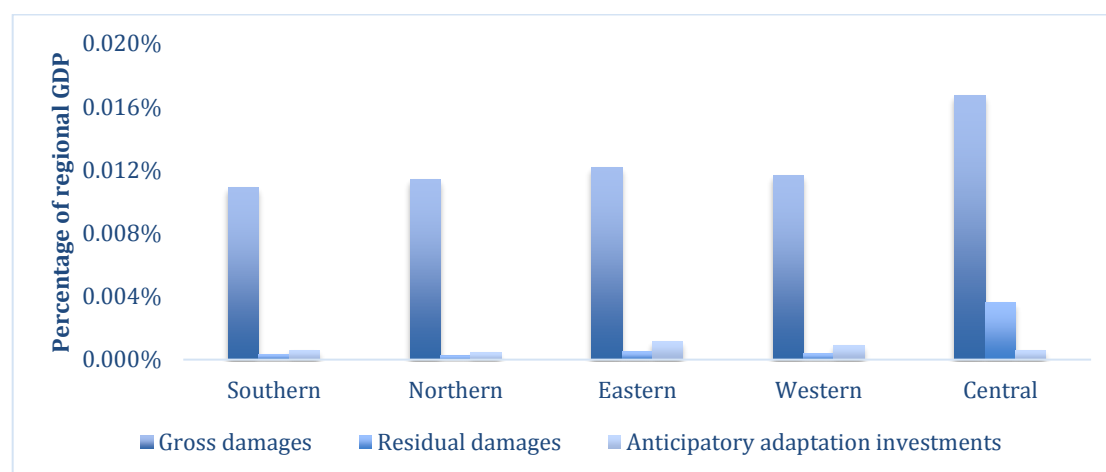


Figure 23 Gross damages, residual damages and anticipatory adaptation investments and reactive adaptation costs in 2050 for each region in the road infrastructure sector for the above 4°C world mitigation path as a percentage of regional GDP.

Tourism

Climate change is expected to impact the tourism sector through increased temperature, climate variability and sea-level rise. Flooding, large waves and heavy storms due to sea-level rise are predicted to impact beaches and to reduce the possibility of wildlife safaris and recreation activities (Agnew & Viner, 2001). Moreover, as temperatures increase, the number of tourism days will decrease for many African countries. Safaris are no longer attractive for tourists when it is severely hot, dry or wet. The tourism impacts will depend on how much tourism contributes to GDP and the effects of climate change on tourism days.

Future impact of climate change on tourism for each country is simulated using the same estimation technique as the Hamburg tourism model (Hamilton et al., 2005). The arrivals of international tourists are re-estimated for African countries using more recent data and taking into account average temperature, per capita income, coastline length and total area of the region. To arrive at figures for total tourism losses, the decrease in tourist numbers in each country due to climate change, derived from the model, is multiplied by income per tourist. Again, the base assumption is that tourism production as a percentage of total production decreases as countries develop. The results show that Northern, Central and Western Africa would suffer gross damages of 0.2 per cent of GDP in 2050 and Southern and Eastern Africa 0.4 per cent of GDP.

This analysis is based on the present relationship between temperature and tourism arrivals and does not consider the additional climate change stimuli that will affect tourism, such as climate variability, storms, flooding, large waves and reduction in beaches. The effect of higher domestic temperatures on international tourist departures is not considered, i.e. increased temperatures worldwide are expected to reduce the

number of tourists from the North vacationing in the South. Domestic tourism is also not considered in this analysis.

Adaptation is assumed to have a limited potential in the tourism sector, where damages can be reduced through increased air-conditioning, the building of swimming pools and the promotion of less climate-dependent tourist activities.

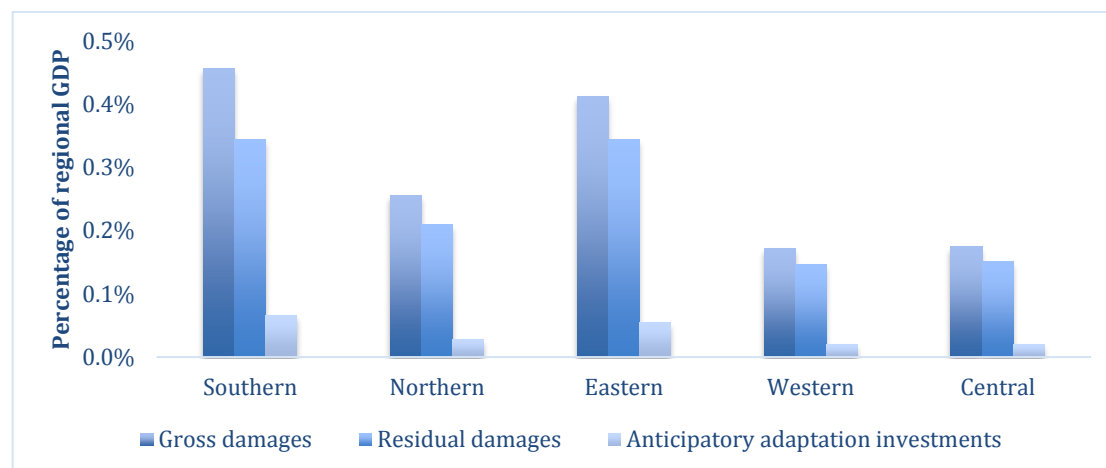


Figure 24 Gross damages, residual damages and anticipatory adaptation investments and reactive adaptation costs in 2050 for each region in the tourism sector for the above 4°C world mitigation path as a percentage of regional GDP.

Water

Precipitation variability, sea-level rise and high temperatures are expected to influence the quality and quantity of water resources in Africa. Changes are projected to vary between regions; apart from Southern Africa, regions are expected to benefit from future increases in water supply; however an even larger increase in water demand is also expected (Kirshen, 2007). Increased demand is driven by the need for irrigation water, the generation of thermal electricity, industrial and domestic use (Parry et al., 2007). Climate change is anticipated to impact the water sector by altering the flow of groundwater, stream water, water runoff and surface water. Kirshen (2007) estimates the additional capital costs needed for water supply to satisfy increased demand, which is also the basis of this assessment. Operation and maintenance costs are not included in Kirshen (2007) but are partially accounted for in the depreciation rate of capital in the AD-AFRICA model. This assessment examines increased water supply for domestic use, commercial use, industrial use and irrigation needs. This approach does not examine the spillover effects to other sectors or the effects of decreased access to water particularly for poorer, rural, communities. It does not consider within-year temporal variation and influences of changes of snow melt on water storage requirements. Gross damages in 2050 range from 0.008 per cent in Northern Africa to 0.05 per cent in Eastern Africa.

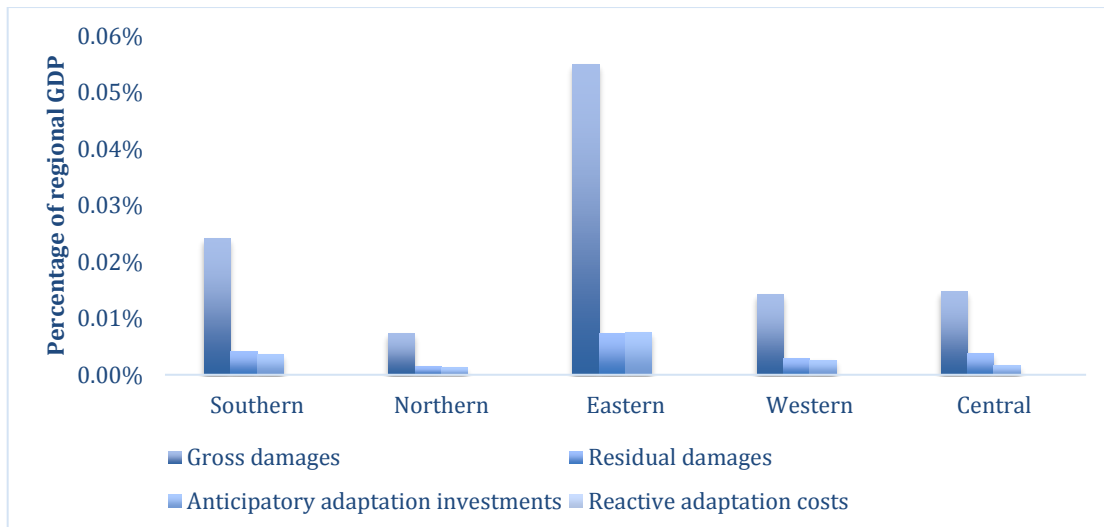


Figure 25 Gross damages, residual damages and anticipatory adaptation investments and reactive adaptation costs in 2050 for each region in the water sector for the above 4°C world mitigation path as a percentage of regional GDP.

Summary

Gross damages are highest for mortality (in the health sector), then for the agricultural sector, followed by tourism and morbidity. The lowest impacts are in the coastal and road infrastructure sectors.

Relatively (i.e. in terms of adaptation costs as a percentage of net damages) adaptation costs (sum of reactive adaptation costs and anticipatory adaptation investments) are highest in the coastal and water sectors. The sector with the highest adaptation potential is the road infrastructure sector, followed by the water, mortality and coastal sector. Adaptation is least effective in the tourism sector, followed by agriculture.

5.3.2 Two worlds

Mitigation policies will have a great effect on the resulting damages and adaptation costs. This report assesses the damage and adaptation cost difference between two mitigation scenarios, namely the below 2°C world (RCP 2.6) and the above 4°C world (RCP 8.5). The differences in temperature between these two scenarios are small until the 2030s and start largely diverging after 2050. In 2050 the differences in gross damages between the two mitigation scenarios are largest in Southern and Eastern Africa, resulting in 70 per cent and 60 per cent more gross damages, respectively, in the above 4°C world. In the other regions, gross damages are 40 per cent higher in the high-warming scenario. In 2100, the increased gross damages in the above 4°C world are much larger, where in Southern Africa gross damages are 420 per cent more. In Eastern Africa, this is 390 per cent more and in the other regions 200 per cent. The reason why differences are largest for Southern Africa is because of the higher relative importance of agricultural and tourism impacts in Southern Africa, which rise steeper with temperature change than the other sectors.

Comparing 2050 and 2100, gross damages in the below 2°C world decrease over time; they are halved by 2100 as compared to 2050 in Eastern and Western Africa. In Eastern Africa, this effect is even stronger, where damages decrease by more than 60 per cent over the 50 years. In Northern and Southern Africa, gross damages remain almost the same. The reason for this decline over time is that the difference in temperature in 2050 and 2100 is negligible in the below 2°C world and, as regions develop over time, mainly the health impacts, but also agricultural, tourism and fishery impacts decrease. In the above 4°C world, gross damages increase as the increasing effect of temperature rise is much larger than the decreasing effect of economic growth. Gross damages increase by 200 per cent in Southern Africa, 100 per cent in Northern Africa 46 per cent in Eastern Africa and 14 per cent in Western Africa. Gross damages are lower for Central Africa in 2100 than in 2050 even in the above 4°C world. This is because almost 90 per cent of the damages in Central Africa fall in the health sector, where damages decrease over time due to economic growth.

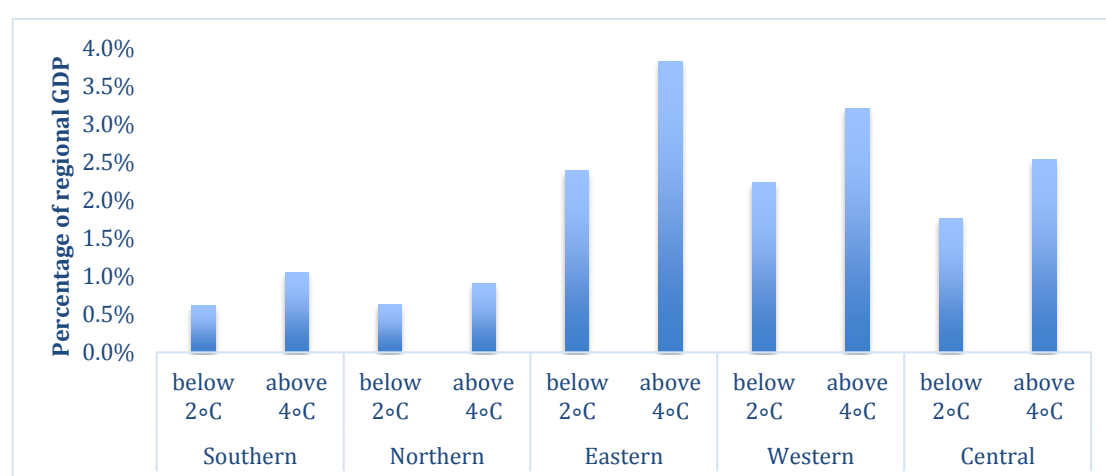


Figure 26 Total gross damages in 2050 for each region for the above 4°C world and the below 2°C world mitigation paths as a percentage of regional GDP.

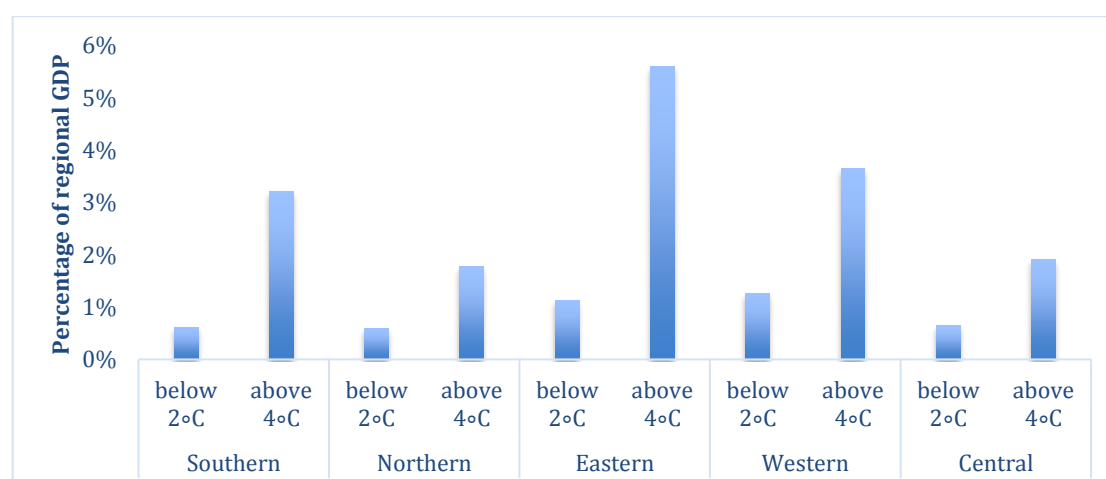


Figure 27 Total gross damages in 2100 for each region for the above 4°C world and the below 2°C world mitigation pathways as percentage of regional GDP.

Figure 25 and 5.9 depict the net damage components (residual damages and adaptation costs) for the two warming scenarios according to region. The difference between net and gross damages represents the climate-change cost-reduction potential of adaptation. Comparing Figure 25 and

Figure 26 to Figure 28 and Figure 29, adaptation has the potential to reduce climate change costs by up to almost 40 per cent, where the potential is higher in the above 4°C world than in the below 2°C world. In the above 4°C world, adaptation potential to reduce damages is even higher in 2100 as compared to 2050. Northern Africa stands to gain the most from adaptation (from 26 per cent to 37 per cent climate-cost reduction depending on the year and warming scenario). After which Central Africa (up to 30 per cent), Eastern Africa (up to 25 per cent) Western Africa (up to 25 per cent) and finally Southern Africa (up to 20 per cent). Similar to gross damages, net damages are higher in the above 4°C world, although the differences are less extreme, ranging between 40 per cent in Northern and Central Africa to 78 per cent in Southern Africa.

Adaptation costs show the same trend of increased costs in the above 4°C world, with increasing differences over time. However, adaptation-cost differences between the two scenarios are much larger than in the cases of gross and net damages. These results are shown in Figure 25 and

Figure 26. In Southern Africa adaptation costs are 190 per cent larger in 2050. In Eastern Africa 140 per cent, in Western Africa 80 per cent and in Central and Northern Africa 70 per cent. For 2100, these numbers increase to between 220 per cent in Northern Africa and 1000 per cent in Eastern Africa. This points to the increasing importance of adaptation needs as temperature changes increase. Compared to residual damages, adaptation costs remain small, where the bulk of adaptation costs are anticipatory adaptation investments.

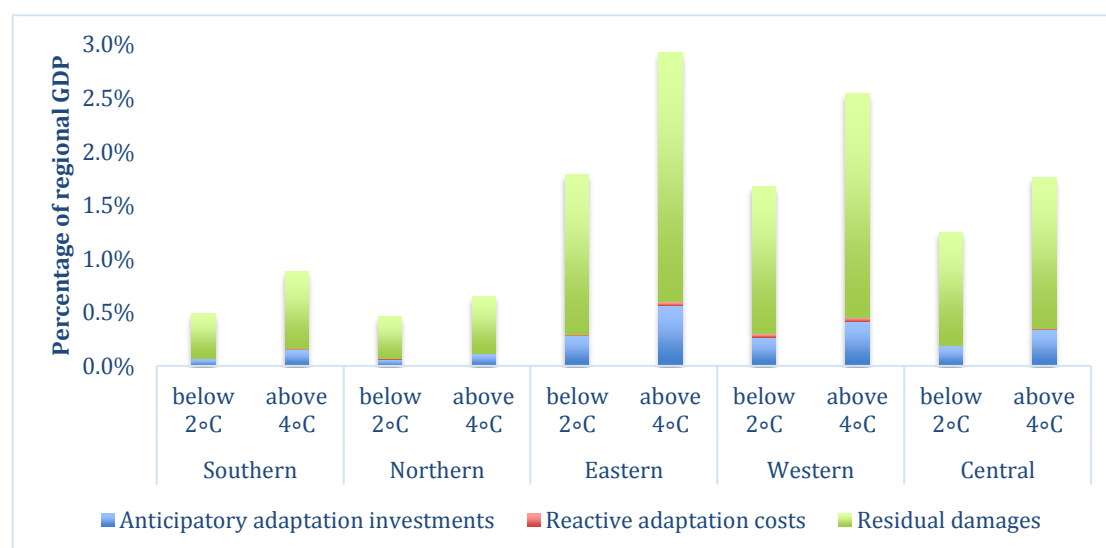


Figure 28 Total net damages: residual damages, anticipatory investments and reactive adaptation costs in 2050 for each region for the above 4°C world and the below 2°C world mitigation paths as a percentage of regional GDP

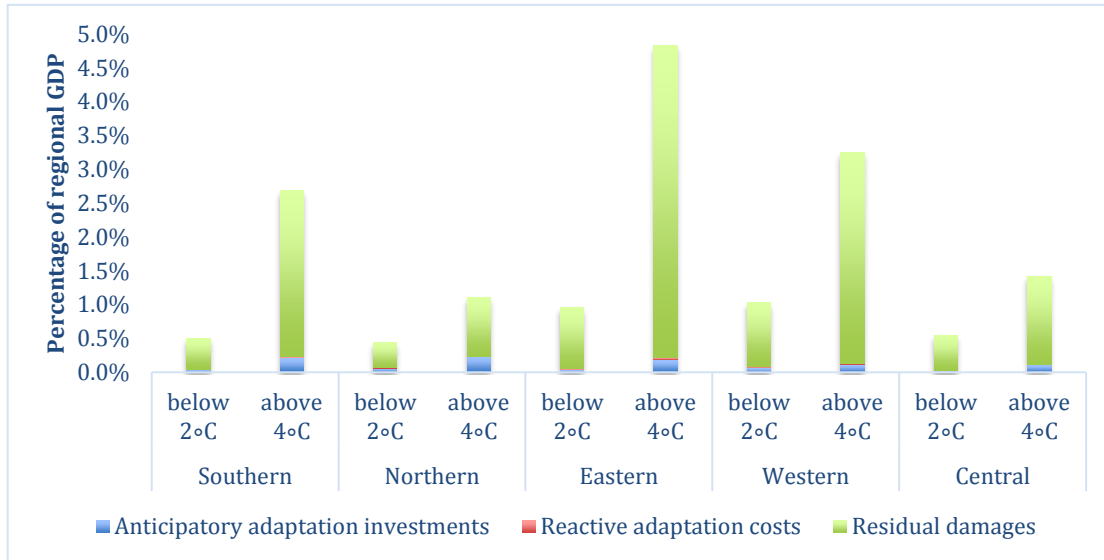


Figure 29 Total net damages: residual damages, anticipatory investments and reactive adaptation costs in 2100 for each region for the above 4°C world and the below 2°C world mitigation paths as a percentage of regional GDP

5.3.3 Dynamics

As shown in the previous section, damages and adaptation costs increase over time as temperature increases. This section examines this issue further. Figure 30 shows gross damages in each sector over time. Tourism and agriculture impacts increase relatively steeply over time. In the health sectors (mortality and morbidity), however, gross damages are stable at first and decrease after 2025 due to the effect of socioeconomic development on the occurrence of vector-borne diseases.

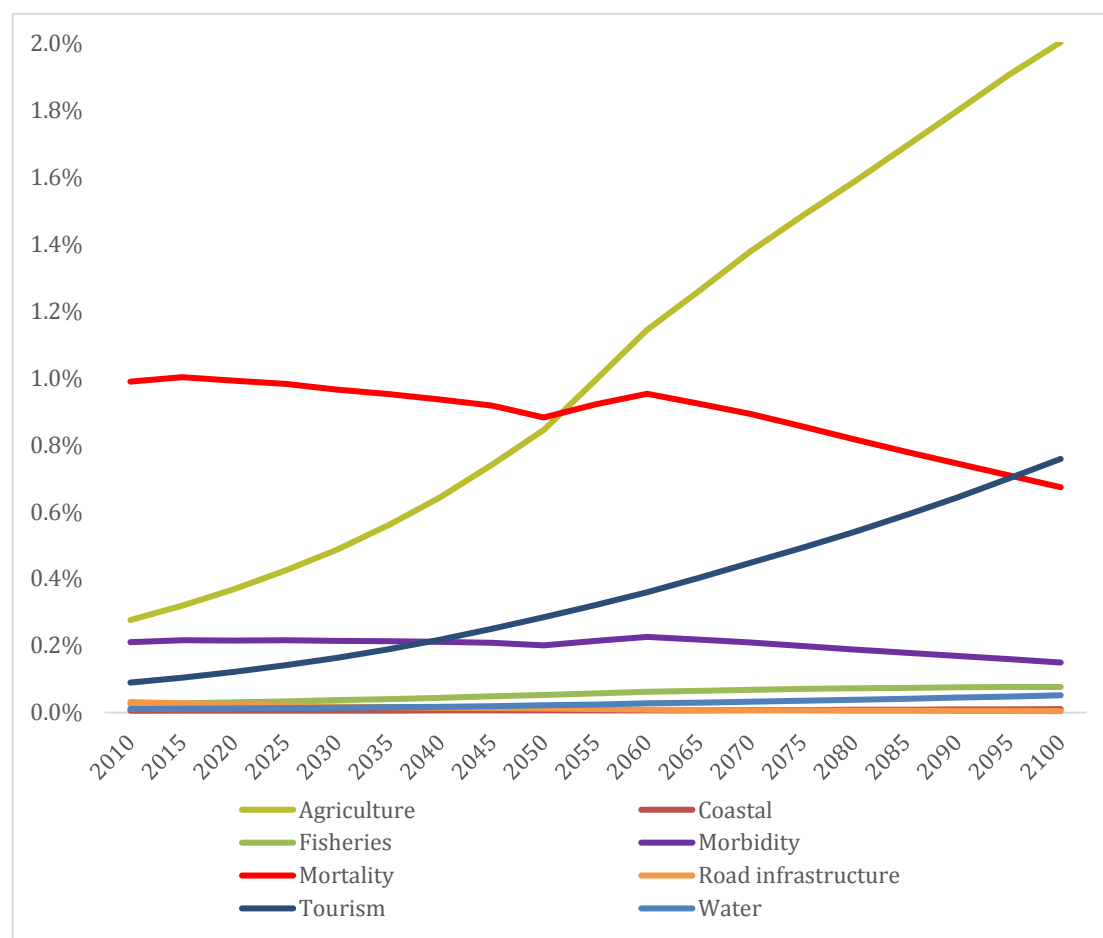


Figure 30 Total gross damages over time for each sector for the above 4°C world mitigation path as a percentage of regional GDP.

5.3.4 Adaptation costs versus benefits

Estimates of future adaptation costs for Africa are dauntingly high. However, the benefits of such adaptation are rarely discussed or estimated. Adaptation benefits easily outweigh costs and without adaptation climate damages will increase tremendously. A shift of focus from adaptation costs to adaptation benefits could help encourage appropriate and timely adaptation policy actions. Figure 31 compares adaptation costs (sum of anticipatory investments and reactive costs) and benefits in each sector to illustrate the substantial benefits to be reaped from good adaptation policies. Adaptation benefits are the difference between gross and residual damages, i.e. the reduction in damages due to adaptation. Adaptation benefits in our model range from 1.4 times costs in the coastal sector to 11 times costs in the road infrastructure sector in 2050. In 2100 adaptation benefits are still much higher than costs, less however than in 2050, ranging from 2.5 times in the coastal sector to 11 times costs in the water sector. This is because the most cost-effective adaptation options are applied first, but as temperature rises, there is an increase in the use of relatively less cost-effective adaptation options.

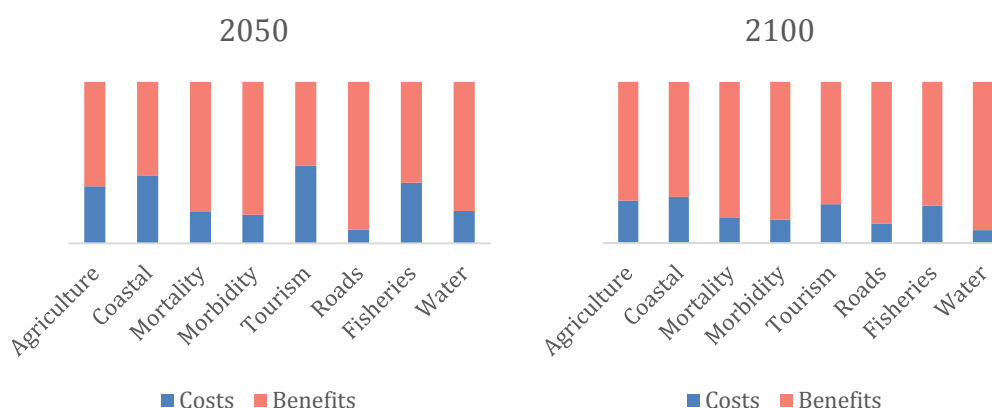


Figure 31 Relative costs and benefits of adaptation in each impact sector in 2050 and 2100 in the above 4°C world scenario.

Adaptation benefits refer to the damage reduction that would be possible if adaptation were applied.²² Figure 5.15 shows the adaptation costs and benefits in billion US\$ for 2010, 2030 and 2050. In the first period, from 2010, adaptation capital needs to be built up, resulting in relatively higher adaptation costs. In Western Africa, the costs slightly outweigh the benefits, but in the other regions benefits are larger, ranging from 1.3 to 3 times costs. This shows that, from the onset, when investments are made, to when longer-term benefits are reaped, adaptation is worthwhile for nearly all regions. However, this is the sum of costs and benefits over the impact sectors, where the costs in individual sectors with high anticipatory adaptation outweigh the benefits within that same sector. With time, adaptation benefits increase as compared to costs and then begin to decrease around 2035. This is due to the increasing relative costs of adaptation over time as temperature rises and as the cheaper adaptation options are exhausted, as explained earlier. The urgency for sound adaptation policies is evident when weighing the adaptation costs and benefits against each other.

²² The symmetric reversal of this concept would be the costs of adaptation inaction.

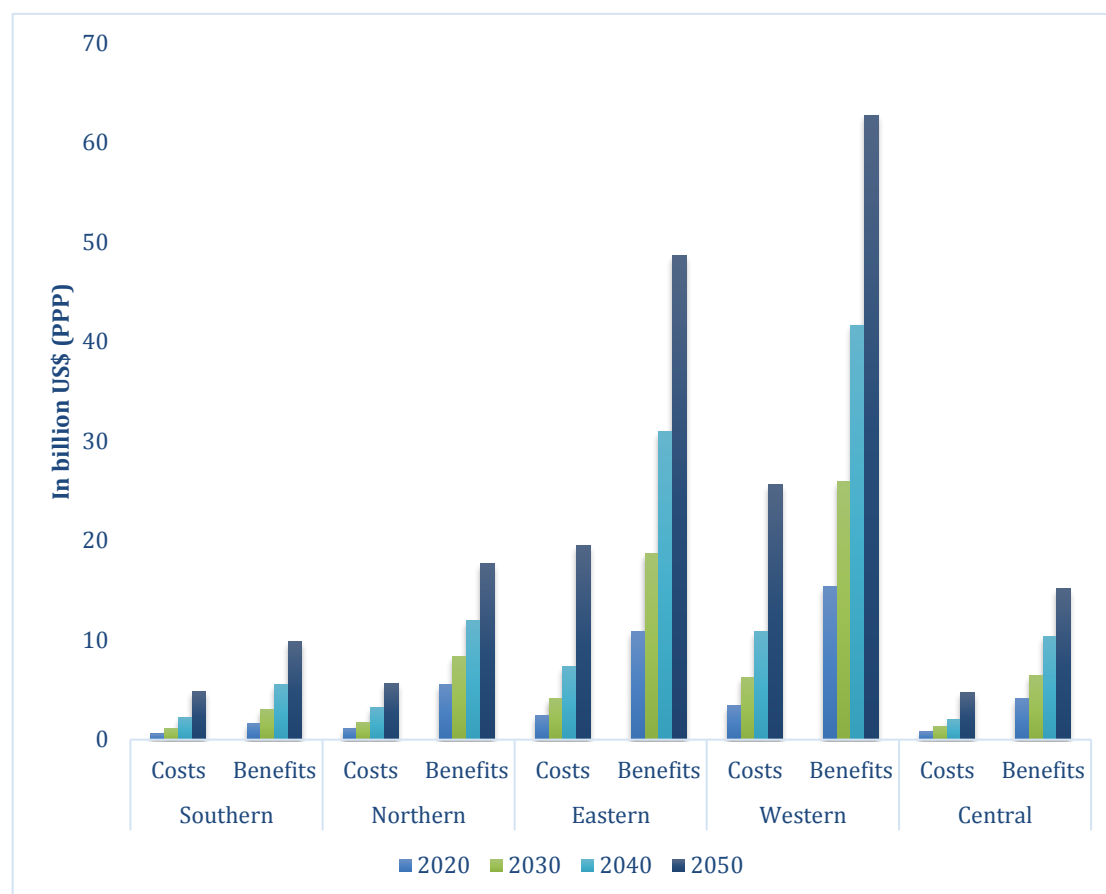


Figure 32 Costs and benefits of adaptation in each region in 2020, 2030 and 2050 in the above 4°C world scenario in billion US\$ (Purchasing Power Parity).

Box 8 Change in climate vulnerability and agricultural income: Mozambique case study
Rogério F. Sitole and Joao Mudema, Centre for Socioeconomic Studies (CESE, Mozambique Agricultural Research Institute (IIAM))

While large-scale models like AD-AFRICA are very useful in providing an overall picture for adaptation priorities and options for large geographical areas, that does not obviate the need for national and local-scale studies to advise stakeholders and national government on adaptation policy strategies. The case study for Mozambique presented here shows how a detailed study of province-level vulnerabilities points to clear interventions for adaptation policies.

Mozambique is widely acknowledged as one of the most disaster-prone countries in the world. The country experiences high levels of climate variability and extreme weather events (i.e. droughts, floods, and tropical cyclones). The cost of climate-related disasters to the national economy was estimated at US\$1.74 billion during the period 1980–2003²³, but the overall economic losses and the impact on the poor are undetermined. Around 80 per cent of the country's population live in rural areas and rely on rain-fed agriculture and the use of natural resources for their survival.

Although significant progress has been made in Mozambique to address climate change and to reduce the impacts of disasters, many challenges still remain to support a proactive and timely response and preparedness. The Mozambique case study offers an opportunity to assess current adaptive capacity or resilience, exposure and sensitivity of households, as well as the factors that influence the current level

²³ Abrams, L. (2008). Long-term Strategic Planning for Disaster Risk Reduction in Mozambique and Malawi.

of vulnerability, and to inform the Government and its partners on actions to reduce the impacts of climate change, focusing on agricultural income.

The overall objective of the study is to analyse the impact of climate change on agricultural income and on vulnerability, comprising three dimensions: level of exposure of households to climate stressors,²⁴ sensitivity,²⁵ and adaptive capacity.²⁶ Additionally, the study highlights the key factors that influence the vulnerability and its impact on household income. Specifically, the study aims to: (a) estimate the level of household vulnerability applying the Household Vulnerability Index (HVI) approach; (b) identify the determinants of household vulnerability; (c) assess the impact of vulnerability on agricultural incomes, and (d) recommend policies that could contribute to reducing household vulnerability and increasing household income.

Methodology

In the first stage of the study we selected four provinces, taking into consideration their historical data on climate disaster occurrence (droughts and floods) combined with the number of the people affected, according to data from the National Agriculture Survey (IAI 2014). For droughts, we selected Sofala and Inhambane provinces and for floods Zambézia and Gaza provinces. In the second stage, we estimated the vulnerability for each household to climatic events (drought and floods) using the Household Vulnerability Index²⁷ (HVI). To estimate the weight of each indicator or dimension, which together compose the HVI, we used Principal Component Analysis (PCA). We created three categories of vulnerability for each climatic event by province (see Table 5.2).

Table 3 Categories of household vulnerability by province and climatic event

Climate event	Province	Categories of HVI		
		High vulnerability	Moderate vulnerability	Less vulnerability
Floods	Zambézia	-2.245 to 0.024	0.027 to 2.286	2.338 to 4.567
	Gaza	-2.071 to 0.226	0.233 to 2.507	2.545 to 4.841
Droughts	Sofala	-1.201 to 0.267	0.273 to 1.715	1.743 to 3.214
	Inhambane	-2.019 to -0.241	-0.232 to 1.489	1.647 to 3.310

Next, we estimated determinants of HVI using the Multinomial LOGIT model. In each model, the base outcome of comparison was the high-vulnerability category against moderate- and less-vulnerability categories. In this comparison, we analysed the probability of the household to become moderate or less vulnerable, taking into consideration the signal observed for each explanatory variable. A positive signal shows an increase in the probability of household becoming moderate or less vulnerable. Then, any future intervention on explanatory variable, the households will have more probability to shift from high vulnerability to moderate or less vulnerability.

To estimate the impact of Climate Change Vulnerability on agricultural income, we adopted a multiple regression model in each province covered by the study. In this model, the dependent variable is the total household agricultural income (sales of crops, livestock and forest products) and the explanatory

²⁴ **Exposure** refers to the degree of climate-change impacts on certain systems that can be represented by long-term observations of a regional local climate and its expected change, including climate variability and extremes.

²⁵ **Sensitivity** defines the degree to which the system is susceptible to direct or indirect climatic impacts.

²⁶ **Adaptive capacity** describes the capability of a system to adapt to real or expected climatic stresses and to cope with their consequences.

²⁷ The approach was developed by FANRPAN (Food, Agriculture and Natural Resources Policy Analysis Network) in 2004. It uses the concepts of vulnerability based on three dimensions: exposure, sensitivity and adaptive capacity.

variables included the level of household vulnerability, as well as the indicators adopted to estimate the HVI. Finally, we estimated the impact of Climate Change Vulnerability on agricultural income in each province covered by the study. A multiple regression model was used, considering as dependent variable the total household agricultural incomes (sales of crops, livestock and forest products), with, as explanatory variables, socioeconomic characteristic and categories of household vulnerability.

Results

Level of household vulnerability (HVI)

Table 5.3 shows that in Zambézia and Gaza provinces, usually affected by flood, about 55 per cent and 61 per cent of households respectively are highly vulnerable. These results suggest that there are many households living under at-risk conditions. In provinces affected by droughts, we found that 66 per cent of households living in Sofala province are highly vulnerable and around 42 per cent of households living in Inhambane province. However, in Inhambane province there are many households (54 per cent) with moderate vulnerability for droughts (Table 5). Very few households in the four study areas could be categorized as less vulnerable.

Table 4 Percentage of household by category of floods vulnerability

Categories of vulnerability	Percentage of households by province	
	Zambézia	Gaza
High vulnerability	55.4	60.9
Moderate vulnerability	42.0	38.4
Less vulnerability	2.6	0.7
Total of households	803	695

Table 5 Percentage of household by category of drought vulnerability

Categories of vulnerability	Percentage of households by province	
	Sofala	Inhambane
High vulnerability	65.8	41.7
Moderate vulnerability	27.8	53.7
Less vulnerability	6.4	4.6
Total of households	471	506

Determinants of household vulnerability

Our results show that in Sofala and Inhambane provinces, areas affected by drought, households have higher probability to decrease vulnerability to droughts if households are headed by women, use AC techniques and own at least one means of transport. Future intervention aiming to boost resilience of the households should take into consideration these factors. Regarding Gaza and Zambézia, areas affected by floods, households have higher probability to decrease vulnerability to floods if households are headed by women, engage in other (non-farm) income activities, have access to communications means (mobile phone, radio, etc.) and own at least one means of transport. Future intervention aiming to reduce the vulnerability of households to floods must consider the aforementioned factors.

Assessing the impact of vulnerability on agricultural incomes

Our models for determinants of agricultural incomes in Sofala and Inhambane show that the level of vulnerability does not have a significant impact on increasing or decreasing the household's agricultural incomes. By contrast, size of cultivated area and diversification of agricultural activities (e.g. hunting, forest, etc.) has a positive effect on increasing household agricultural incomes in these areas. In addition, in Sofala province, households that do not grow cash crops tend to have lower agricultural incomes.

On the other hand, of the provinces prone to floods, Zambézia and Gaza, we found only in Zambézia an impact of vulnerability level on household agricultural incomes. In this province, households with

less vulnerability to floods tend to have higher agricultural incomes when compared with highly- and moderately-vulnerable households. However, in Gaza province, households that have more members with credit access or that use fertilizers tend to obtain higher incomes from agricultural activities, whilst in Zambézia, households that do not grow cash crops tend to have lower agricultural incomes.

Key findings

- In Mozambique, rural households are highly vulnerable to floods and droughts;
- The results of the study show that vulnerability is strongly determined by socioeconomic factors. In drought, these factors include sex of household head, use of agricultural conservation techniques and ownership of transport, while in areas prone to floods, in addition to the sex of household head and ownership of transport, other factors that influence vulnerability are the number of household members engaged in non-farm activities and ownership of communication means.
- In general, the level of vulnerability does not show a significant impact on household agriculture incomes, except in Zambézia province (prone to floods) where less vulnerable households tend to have higher agricultural incomes. However, other factors such as size of cultivated area, credit access, use of fertilizers, grow of cash crops tend to increase agricultural incomes.

Recommendations

From the findings of this research, the following recommendations are made to the Government and its partners.

- To overcome climate change impacts and boost the resilience of households, any intervention has to take into consideration gender aspects, promotion of non-farm activities, promotion of agricultural conservation technologies (particularly in areas prone to droughts) and to expand the communication service (e.g. mobile network, broadcasting radio, etc.);
- To increase agricultural income of households in disaster-prone areas, the findings suggest that efforts should be made to promote the use of agricultural equipment as a strategy to expand cultivated area, and also to facilitate credit access and the use of fertilizers.

5.4 Conclusions and policy recommendations

5.4.1 Conclusions

This chapter examined the long-term dynamics of damages and adaptation costs in Africa on a large scale. Two country case studies show how national and local studies can complement such large-scale assessments by indicating key intervention points and lessons learned.

Looking at the dynamics of damages, we find that damages decrease through economic development, both as percentage of GDP and in absolute terms. As countries develop, they become less dependent on tourism, agriculture and fishery, reducing these impacts in terms of percentage of GDP. Moreover, health impacts are severely reduced through economic growth, when it brings better access to medical care, clean water and improved sanitation. Given the dominance of health-sector impacts in total impacts, this results in a decrease in total impacts in the below 2°C world over time. Temperature rise is limited and hence the impact-dampening effect of economic growth is larger than the temperature effect, resulting in decreasing damages. In the above 4°C world, the temperature-increase effect is larger, resulting in an increase in damages over time. This is, however, not the case for Central Africa, where damages decrease over time also in the above 4°C world, owing to the high health impacts in this region, which decrease with economic growth.

The difference in damages between the below 2°C world and the above 4°C world is dramatic, where gross damages are up to 70 per cent higher in 2050 (in line with macroeconometric-based modelling results in chapter 3) and 420 per cent in 2100 under

a high-warming scenario. This shows how global mitigation efforts to avoid high-warming scenarios will affect Africa.

per cent. As damages increase, more adaptation is needed, resulting in higher adaptation costs. The ratio of adaptation benefits to costs decreases slightly over time as less cost-effective adaptation options are applied. Adaptation benefits, however, always greatly outweigh costs. As damages increase, so do adaptation costs, but at a higher rate, i.e. adaptation costs are more sensitive to temperature than damages.

This chapter also outlined the limitations of a continent-wide modelling approach, even with the much higher detail and broader data and literature evidence base of the AD-AFRICA model than previous modelling efforts, in particular for Africa. A case study for Morocco for the agriculture sector illustrates how many adaptation options have been developed at local to national level, and how such options are incorporated in national policies and programmes and hold key lessons for other countries and future policy development cycles. Finally, a case study for Mozambique shows the value of looking far beyond GDP to measure the impacts of climate change and benefits of adaptation. Again, at a national and local level, targeted research shows how vulnerabilities of rural communities can be strengthened through key intervention points.

Though models such as AD-AFRICA can give insights into the dynamics of climate damages and adaptation options, their results need to be interpreted with caution. There are obvious limitations to such models, which need to be kept in mind when examining their results. Firstly, and most importantly, this model does not include uncertainty, which plays such an important role in climate change. All elements of the climate change problem inherently include uncertainty, where future predictions are precarious. Estimates of damage impacts and adaptation costs and benefits include high levels of uncertainty. These specific damage impacts have been estimated on the basis of limited data sources and adaptation costs, while benefits are based on technical adaptation options, which are likely to overestimate benefits and underestimate costs. Moreover, the further into the future estimates go, the more uncertain they become. Secondly, this model does not include many impacts such as extreme events or impacts on energy or ecosystems. Thirdly, this model assumes perfect information and foresight.

5.4.2 Policy recommendations

1. efforts are needed to secure at-scale, predictable funding. These could include:
 - (a) Fostering international support from multilateral sources (Green Climate Fund, for example) and bilateral sources; African countries need to further engage in Green Climate Fund readiness programmes towards the development of fundable applications.
 - (b) Further exploring the potential of innovative sources and supporting development banks' efforts to increase funding towards adaptation and assisting in scaling-up non-conventional financial instruments (guarantees, bonds, debt swaps, etc.) to support adaptation measures.
2. To ensure that future development is climate-resilient, policymakers are advised to further integrate and mainstream adaptation to climate change into development

planning. Adaptation options with mitigation and/or development co-benefits should be encouraged, and reciprocally, such as the deployment of renewable energy sources, which contribute to mitigating emissions as well as strengthening the resilience of the energy sector to heat extremes and droughts.

3. In order to avoid overlaps and inefficiencies, where applicable, countries could improve the connections and complementarities between climate-change adaptation and disaster-risk management, to further reduce the consequences of extreme-weather events on livelihoods and communities. In line with this objective, and also where applicable, the institutional framework could also be simplified and streamlined to facilitate complementary implementation of adaptation and disaster-risk management strategies.

6. Opportunities and co-benefits from climate action

6.1 Introduction

Chapters 3 and 4 assessed the risk that climate change imposes on economic growth and development across Africa in the coming decades. Chapter 5 presented an opportunity to reduce these risks by implementing optimal adaptation measures over the rest of this century. While reactive and anticipatory adaptation (and mitigation) incurs immediate economic costs, these costs should be weighed against current and future benefits.

Identifying and quantifying opportunities is important for both ex-ante and ex-post policy implementation. Estimates of opportunities have significant implications for Governments, as these can guide investment decisions, boost political support and accelerate climate action. For instance, Escaleras & Register (2011) conclude that policies that reduce the negative impact of natural disasters – such as hazard-sensitive building codes and zoning or investments in early-warning and post-disaster recovery systems – can improve a Government’s ability to attract foreign direct investments (FDI). Health co-benefits can be used to generate support for climate policies (Sauerborn et al., 2009). The intended nationally determined contribution (INDC) of Kenya includes suitable opportunities, such as access to technologies and extension of climate-smart agriculture (CCAFS East Africa, 2015). More reliable and cleaner energy supply is often identified as an important co-benefit of climate policies (IEA; OECD, 2014; Rao et al., 2013).

This report complements the results of chapter 4 by looking more specifically into the mitigation opportunities,²⁸ with particular interest in co-benefits or the “positive effects that a policy or measure aimed at one objective might have on other objectives”.²⁹ In this case, this refers to the possible spillover effects of mitigation on other sectors beyond the initially-intended climate-related objectives. The chapter looks into possible co-benefits of mitigation through improved energy security from the expansion of renewable energy sources, the associated increase in employment, and finally, the increased health benefits from reduced air pollution. By looking at co-benefits, this report aims to give a better view of the factors that should also be considered when looking into mitigation opportunities. The selection of co-benefits to assess is dictated by data availability and relevance for development in the African region.

The quantitative results are presented in section 6.2. Box 9 presents a case study on Togo, section 6.3 wraps up with conclusions and the outlook for the future, and section 6.3.2 lists policy recommendations based on the findings and insights of these analyses.

The chapter considers the advisability of achieving sustainable growth and development by investing in the emerging renewable energy sector, which has high

²⁸ Adaptation opportunities are defined as “factors that make it easier to plan and implement adaptation actions, that expand adaptation options, or that provide ancillary co-benefits” (Klein R.J.T. et al., 2014). “Mitigation opportunities” are assumed to be defined analogously.

²⁹ IPCC (2014) definition of opportunities and co-benefits: “The positive effects that a policy or measure aimed at one objective might have on other objectives, irrespective of the net effect on overall social welfare. Co-benefits are often subject to uncertainty and depend on local circumstances and implementation practices, among other factors. Co-benefits are also referred to as ancillary benefits.” (page 1762).

potential for growth, and using available human and natural resources to improve energy security in Africa. This increase in energy security increases the use of renewable resources and will come at the expense of lowering the use of fossil sources. The chapter quantifies the net gain in energy security and employment corresponding to this shift in the energy mix. Finally, the chapter looks into the impact on health conditions of the reduction in emissions from the change in the energy mix. The improvement in health and wealth of the human capital and the increase in physical capital from investments made in the energy sector feeds into a long-term improvement in the economy. The report focuses on the projections of co-benefits up to 2050.

6.2 Quantified assessment of mitigation co-benefits for Africa

The quantified assessment of each co-benefit is based on the differences in key indicators between two climate scenarios from the LIMITS project database³⁰: the *Reference Policy* scenario (RefPol), and the *Reference Policy 450* scenario (RefPol-450). The RefPol scenario assumes a world without climate policy beyond implementation of the 2009 Copenhagen pledges, which are consistent with up-to-date estimates of the effects of more recent reduction pledges and INDCs associated with the 2015 Paris Agreement (UNEP, 2015). This leads to a global-mean temperature increase above pre-industrial levels of about 3.4°C by 2100. The *Reference Policy 450* scenario (RefPol-450) assumes additional mitigation post-2020, consistent with holding global temperature increase below 2°C from pre-industrial levels. RefPol serves as a baseline scenario, against which the more stringent RefPol-450 scenario is compared. Further details are available in Annex 8-12.

For consistency of assumptions and by reason of the availability of sufficiently detailed model data, all projections used in this chapter are from the REMIND Model and, because of model characteristics, are limited to sub-Saharan Africa (SSA), excluding South Africa;³¹ For the discussion on health co-benefits, we used the MESSAGE Model results for the same region, again for reasons of data availability.

6.2.1 Improved energy security

Meeting the growing energy demand is one of Africa's biggest challenges (Foster & Briceño-Garmendia, 2009). Currently, about 60 per cent of people living in sub-Saharan Africa have no reliable access to clean and affordable energy sources, especially electricity (AfDB, 2014). The IEA³² projects that between 2010 and 2040, energy demand in Africa will grow by 80 per cent on account of an economy that will grow four times and a population that will double. Enhanced electricity access will require expensive grid expansion (Lucas et al., 2015). In rural areas, mini-grid or off-grid solutions might therefore be cost-effective (Szabó et al., 2011). According to

³⁰ Low climate Impact scenarios and the Implications of required Tight emission control Strategies (LIMITS): the project description can be found here: <http://www.feem-project.net/limits/> and the actual database is hosted here: <https://tntcat.iiasa.ac.at/LIMITSDB/dsd?Action=htmlpage&page=about>.

³¹ Integrated Assessment Models (IAMs) like REMIND or MESSAGE usually deliver results on a level of 10–20 global regions. More details can be found here: https://tntcat.iiasa.ac.at/LIMITSPUBLICDB/static/download/LIMITS_10+1_regions.pdf.

³² <https://www.iea.org/newsroomandevents/pressreleases/2014/october/energy-sector-is-key-to-powering-prosperity-in-sub-saharan-africa.html>.

Bazilian et al. (2012), universal electricity access in SSA (excluding South Africa) would require about 374 GW of capacity installed by 2030. In 2012, SSA excluding South Africa has only 28 GW of installed generation capacity.³³

Higher levels of economic development are generally associated with increased energy consumption (figure 5.1). Currently, the dominant commercial primary energy sources are unsustainable, both in the sense that the stock of non-renewable primary energy sources (fossil fuels) is declining and the carbon emissions produced by these sources have significant and negative environmental impacts. Non-commercial energy sources like firewood, crop residues and dung do play a significant role in many African countries. Collecting firewood, as the most important of these sources, has adverse impacts on the environment since extraction is above sustainable levels in many areas, and also on the time allocation of people, since time spent on collecting firewood cannot be spent for other, more productive activities like, for instance, schooling. In order to achieve sustainable development goals, policymakers resort to alternatives and approaches in achieving growth targets that are vital for poverty reduction and overall development, without sacrificing environmental considerations. Among the alternatives are an increased investment in clean, renewable energy and an increase in energy efficiency, which help increase energy security.

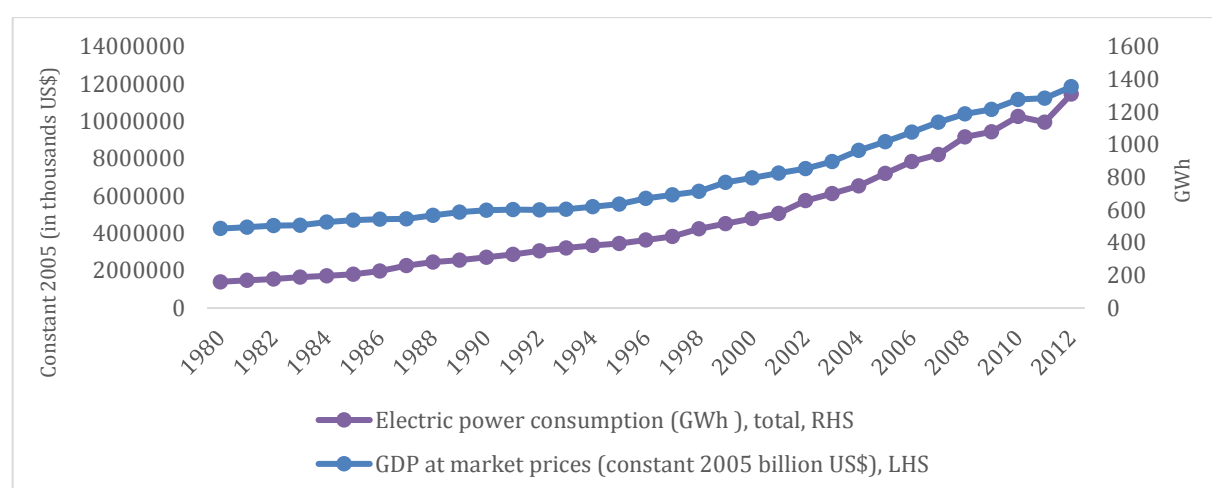


Figure 33 GDP in constant 2005 US\$, Electric Power Consumption³⁴ in Africa. Source: World Bank World Development Indicators

Investment in energy supply

Up to today, most investments in the energy sector go into the exploitation of fossil fuels for export (IEA, 2014). Figure 34 below shows the projected investment in energy supply for Africa for the next decades for the two scenarios – one with progressively high reliance on fossil fuel use (RefPol), and the other with increased energy support from renewable energy sources (RefPol-450). While growth in energy investments in the RefPol scenario averages at about 6.4 per cent, the share in GDP remains close to only 2.0 per cent for the entire period. For RefPol450, energy investment growth is

³³ Energy in Africa: Overview

<http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/AFRICAEXT/EXTAFRREGTOPENERGY/0,,menuPK:717332~pagePK:51065911~piPK:64171006~theSitePK:717306.00.html>.

³⁴ Data not available for Djibouti.

slightly higher at 7.3 per cent and the share of energy investments to GDP progresses from 2 per cent to a high of 3.4 per cent in the 2040s.

One of the main considerations in the move toward renewable energy technologies is their higher initial costs as compared to fossil fuel-based technologies. IPCC (2014a) notes that these higher costs present a challenge for integrating renewable energy into energy systems. However, according to the IEA World Energy Outlook (IEA, 2014), projections of average capital costs of investment in renewable energy show a decline in the costs for biomass, geothermal, wind, and most of all, solar. On average, for instance, the RefPol-450 scenario projects an annual reduction of 4.5 per cent of solar investment capital cost from 2012 to 2020 and 2.2 per cent reduction from 2020 to 2035, thereby reducing the cost of investment to about half by 2035 as compared to 2012. IRENA (2012a) attributes the potential for cost reductions to the removal of supply bottlenecks and increased competition among suppliers. Larger reductions in cost could also be achieved through technological improvements such as “learning-by-doing, improvements in the supply chain, increased manufacturing economies of scale, competition and more investment in R&D”.

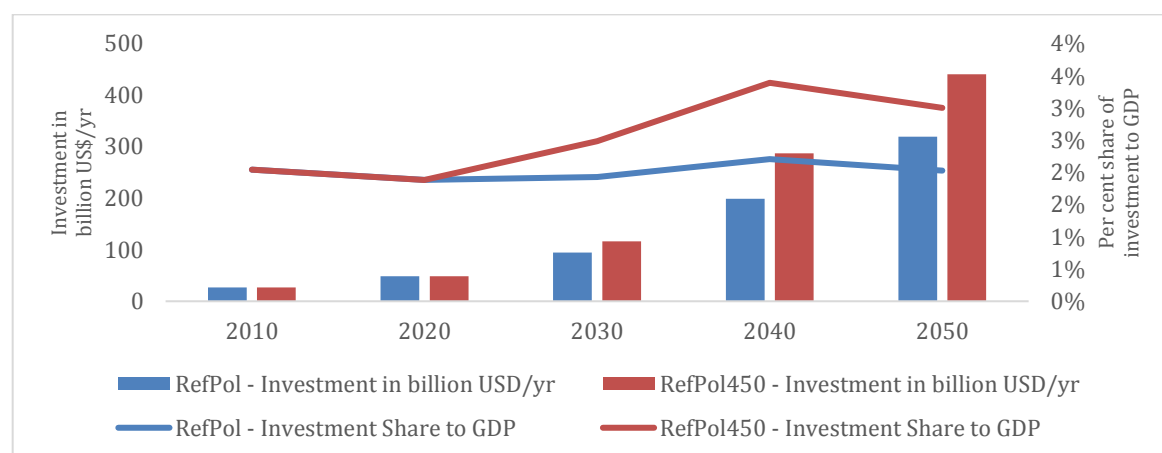


Figure 34: Investment in energy supply in Africa, REMIND model. Source: LIMITS database, own calculations

Energy security, defined as the “uninterrupted availability of energy sources at an affordable price”,³⁵ goes beyond increasing energy supply through investments. Sub-Saharan Africa (SSA) is currently a net exporter of energy (Lucas et al., 2015), despite a majority of the population having no access to modern sources of energy. While energy self-sufficiency, computed as the percentage of domestic energy consumption covered by domestic production, may be used as one of the indicators of energy security, this report also considers self-sufficiency net of exports; that is, if domestic production that is available to the domestic market is still sufficient for consumption. We acknowledge the reality that exports in SSA will be likely to continue because of attractive global prospects.

Figure 35 shows that energy self-sufficiency in the RefPol-450 scenario is significantly higher than in the RefPol scenario, but production still falls short of energy demand for both scenarios. It can be observed that in RefPol-450, energy production is still

³⁵ <http://www.iea.org/topics/energysecurity/>.

adequate for domestic consumption in the 2030s and starts to fall short of energy demand by the next decade. In contrast, the RefPol scenario sharply declines in both self-sufficiency and self-sufficiency net of exports starting in 2030. The lower self-sufficiency rate for the RefPol scenario is primarily driven by the high reliance on fossil fuels, the extraction rate of which is much slower than the increase in demand.

Energy consumption is expected to grow in SSA at a faster pace than energy extraction. The model underlying this analysis also shows a quick transition from traditional biomass to modern sources of energy at a faster pace than estimated by other models in this field (Lucas et al., 2015). It also shows that an important reason for the higher level of energy self-sufficiency is the much lower energy demand due to higher energy prices and higher energy efficiency. This lower demand is then met nearly without the use of coal.

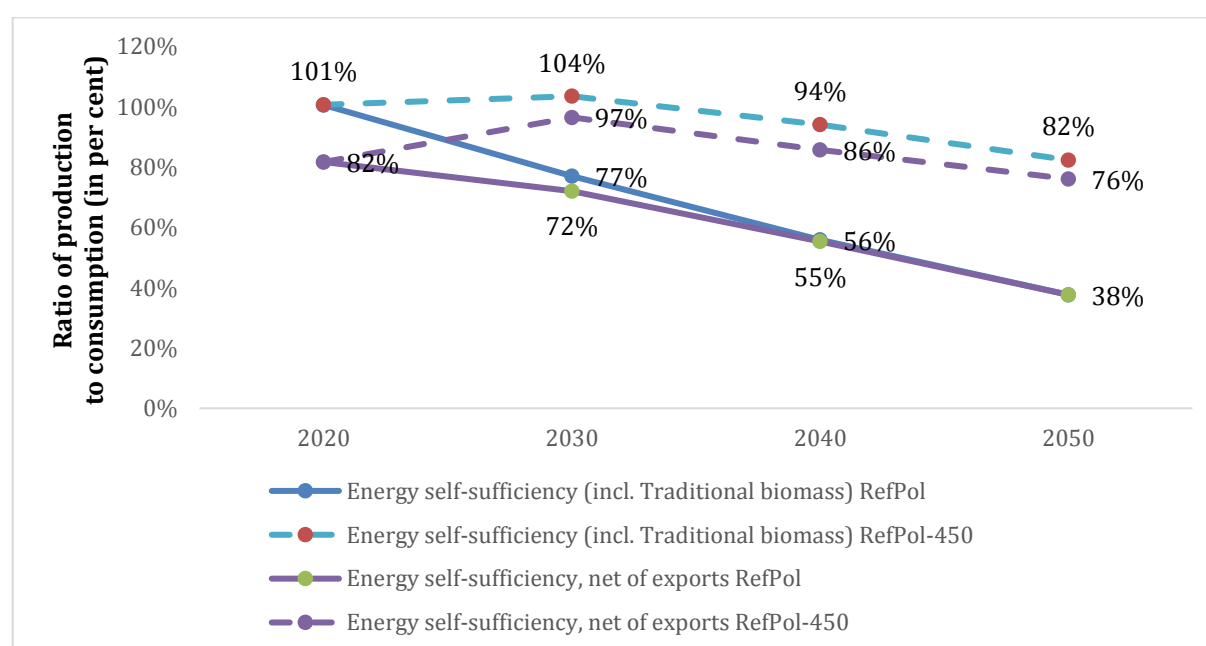


Figure 3 Primary energy self-sufficiency (including traditional biomass) indicator, and energy self-sufficiency, net of exports in sub-Saharan Africa (SSA) excluding South Africa in the REMIND model. Source: LIMITS database, own calculations

Insufficient domestic energy production may be resolved through imports. Import dependency, a complementary indicator to self-sufficiency as it is broken down by energy source, is important for assessing energy security because it represents the degree of vulnerability to external factors, e.g., international price fluctuations and global supply disruptions (UNECA, 2015). Figure 4 suggests higher import dependency in 2050 for the RefPol scenario as compared to the RefPol-450 scenario, assuming no trade exists for renewable energy, with the exception of oil.

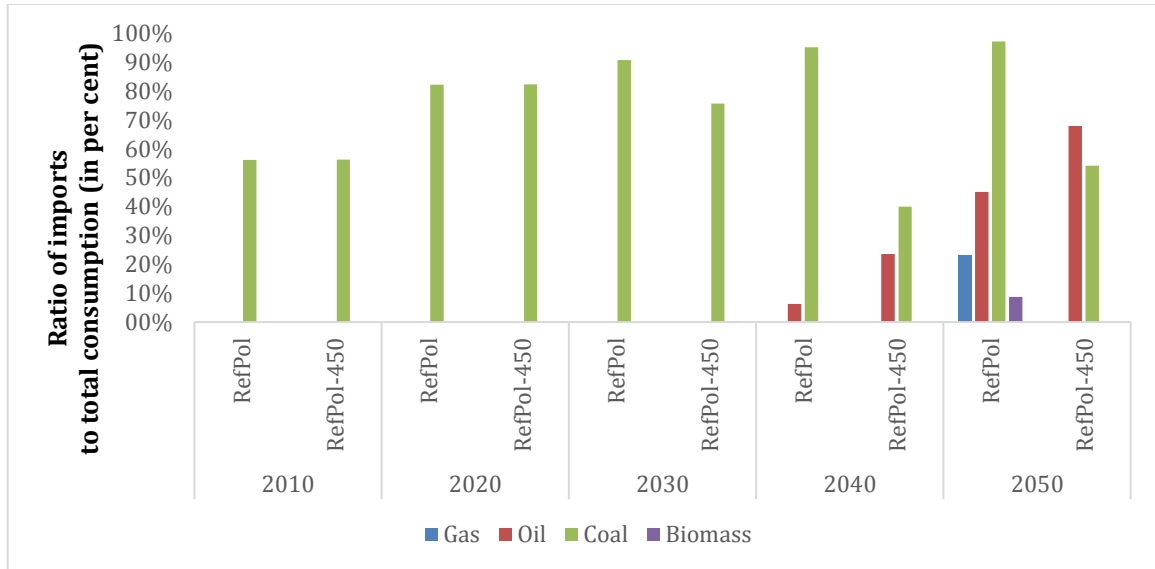


Figure 4: Import dependency (ratio of the volume of imports to total consumption per energy source). Source: LIMITS database, own calculation

Energy intensity

A graphical representation of energy intensity, calculated as the units of domestic energy consumption per unit of GDP, is presented in Figure 5. Energy intensity is a measure of an economy's efficiency in the use of energy. The energy intensity branches out to a lower ratio for RefPol-450 as compared to RefPol, thereby signifying a higher level of energy efficiency starting in 2030. Higher efficiency can be attributed to an improvement in production processes, which can be influenced by technological improvements from increased investment, as well as higher prices that may create pressures to maximize the use of every unit of energy to produce an output.

Referring back to the investment schedule in Figure 34, RefPol scenario's investment share in GDP remains relatively flat; while that of RefPol-450 exhibits an increasing share over time. Given the investments in energy supply shown in Figure 5, it can be deduced that the higher level of investment in RefPol-450 allows for a higher level of energy efficiency.

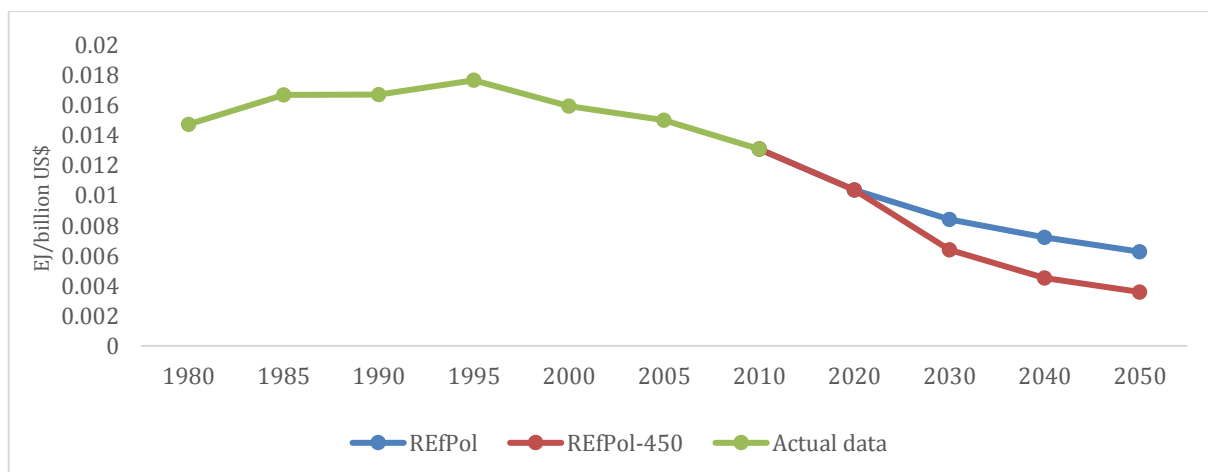


Figure 5: Energy intensity (EJ/Billion US\$) in sub-Saharan Africa Source: World Bank World Development Indicators; US EIA International Energy Statistics; LIMITS database; own calculations

Conclusions on energy security

Energy security is important for both economic growth and development. The interdependence of the two presents an opportunity for a progressive loop: while energy security supports the expansion of economic sectors and the production of higher levels of output, economic growth also influences the demand for more energy consumption and the corresponding investment in the energy sector needed to meet these demands in the future. Ensuring energy security also reduces or prevents upward pressure on prices, which affects access to electricity that is also key in improving welfare. Currently, the World Bank³⁶ identifies three key issues in Africa's energy sector: (1) low access and insufficient capacity, as only 24 per cent of the population in SSA have access to electricity, (2) poor reliability due to power outages and limited back-up generation, and (3) high costs due to high tariffs and low reliability of publicly-provided electricity, which pushes firms to operate their own diesel generators at two to three times the cost.

The analysis recognizes the importance of investments in energy supply as a driver of growth in production, as well as its role in increasing efficiency. That is, while higher investment is needed to increase production of energy, less energy may be needed in the future owing to efficiency improvements. Even with projections suggesting that energy supply in Africa will no longer be sufficient for the growing energy demand for RefPol-450 scenarios starting in 2040 and a decade earlier for RefPol scenario, the energy gap³⁷ may not be as severe, as increases in efficiency will require less consumption for the same level of output. Also, our analysis focuses on SSA at aggregated level, even though energy-related indicators can vary widely across different countries

6.2.2 Employment opportunities

³⁶ The World Bank and Energy in Africa. Accessed 18 March 2016. Available at <http://web.worldbank.org/WBSITE/EXTERNAL/COUNTRIES/AFRICAEXT/0,,contentMDK:21935594~pagePK:146736~piPK:146830~theSitePK:258644,00.html>.

³⁷ Difference between domestic demand and domestically-produced supply.

Introducing renewable energy technologies and changing the primary energy mix require that not only should investments be considered, but also the critical impact on employment. This section focuses on the direct employment generated by the shift in the electricity mix towards renewables. To this end we compare the RefPol-450 to the RefPol scenario, by multiplying the installed capacity and the additional annual installed capacity, with the adjusted employment factor – taken from Rutovitz & Harris (2012) - for Operations and Maintenance (OM) and Manufacturing, Construction and Installation (MCI), respectively, for each energy source. The two activities differentiate between employment that is created only by building the energy system (MCI), and thus will only last for the estimated period of construction, and employment needed while the installation is actually supplying energy (OM).

The adjusted employment factor refers to the product of the employment factor for each type of energy source, the regional multiplier for Africa to correct employment factors that are estimated for the OECD and to account for different levels of development and labour productivity, and the employment factor decline rate to adjust for learning rates or the “reduction in employment per unit of electrical capacity as technologies and production techniques mature” (Rutovitz & Harris, 2012) (Table 6).

Energy source	Construction time (in years)	2020		2030		2040		2050	
		MCI	OM	MCI	OM	MCI	OM	MCI	OM
Coal	5	11.9	0.3	11.9	0.3	11.9	0.3	11.9	0.3
Gas, oil, and diesel	2	2.5	0.2	2.5	0.2	2.7	0.2	2.7	0.2
Nuclear	10	32.0	0.7	32.0	0.7	32.0	0.7	32.0	0.7
Biomass	2	7.2	12.9	7.2	12.9	7.9	13.3	7.9	12.4
Hydro	2	4.5	0.4	4.5	0.4	4.5	0.4	4.5	0.5
Wind	2	25.2	1.6	25.2	1.6	27.6	1.5	27.6	1.1
PV	1	32.2	1.6	32.2	1.6	35.2	1.1	35.2	0.7
Geothermal	2	10.8	2.8	10.8	2.7	11.8	1.5	11.8	0.7

Table 6: Adjusted employment factors for Africa.

Source: Author’s calculation using multipliers from Rutovitz & Harris (2012)

Employment factors for renewable energy generation generally appear to be higher than fossil energy, both for MCI and OM activities. However, the rate of employment factor decline is also much higher in renewables, suggesting that it is still in the early stages of development and that the rate of labour productivity improvements in learning-by-doing and technological advances will be faster than the alternative.

Figure 6 compares the different energy mixes used for electricity generation between the two scenarios. For the RefPol scenario, a sharp decrease can be observed in electricity from gas and hydropower sources; while energy from other sources increases, particularly for coal and gas. Coal and gas account for about 80 per cent of electricity generation by 2050 in the RefPol scenario. On the other hand, the RefPol-450 scenario shows a declining share of coal, oil, and gas, as well as hydro-sourced electricity from 50 per cent in 2010 to 29 per cent in 2050. Energy shares that increase in the RefPol-450 scenario are nuclear, wind, and solar. Wind and solar account for only 5 per cent of electricity generation in 2010 and increase to 53 per cent in 2050 in the RefPol-450 scenario. The decline in hydro-sourced power for both scenarios may be explained by the projected increasing cost of investment for hydropower (LIMITS), as well as the increasing rate of employment needed for every MW produced, as noted by Rutovitz & Harris (2012).

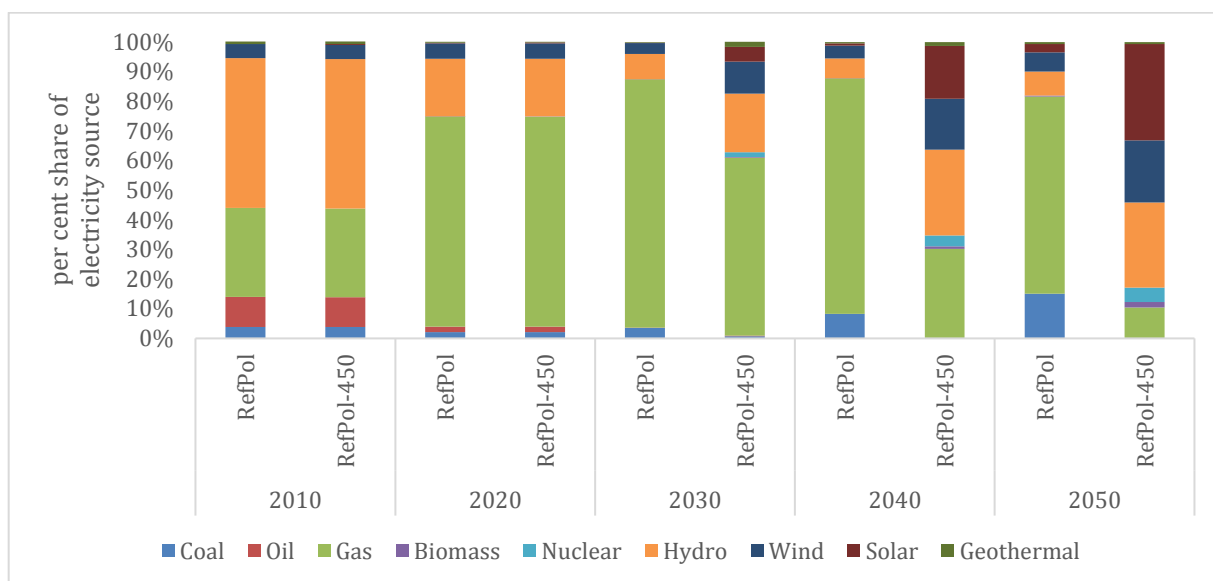


Figure 6: Per cent share of electricity source in total electricity generated. Source: LIMITS database

Direct employment estimates suggest that MCI-related employment will be three times higher in RefPol-450 as compared to RefPol in 2040, and six times more in 2050, potentially creating 35.6 million employment opportunities. For OM-related employment, RefPol-450 provides 30 per cent more opportunities than RefPol in 2040 and 254 per cent more in 2050. Interesting to note is the downward-sloping employment trend for OM in the RefPol scenario, despite the increase in consumption.

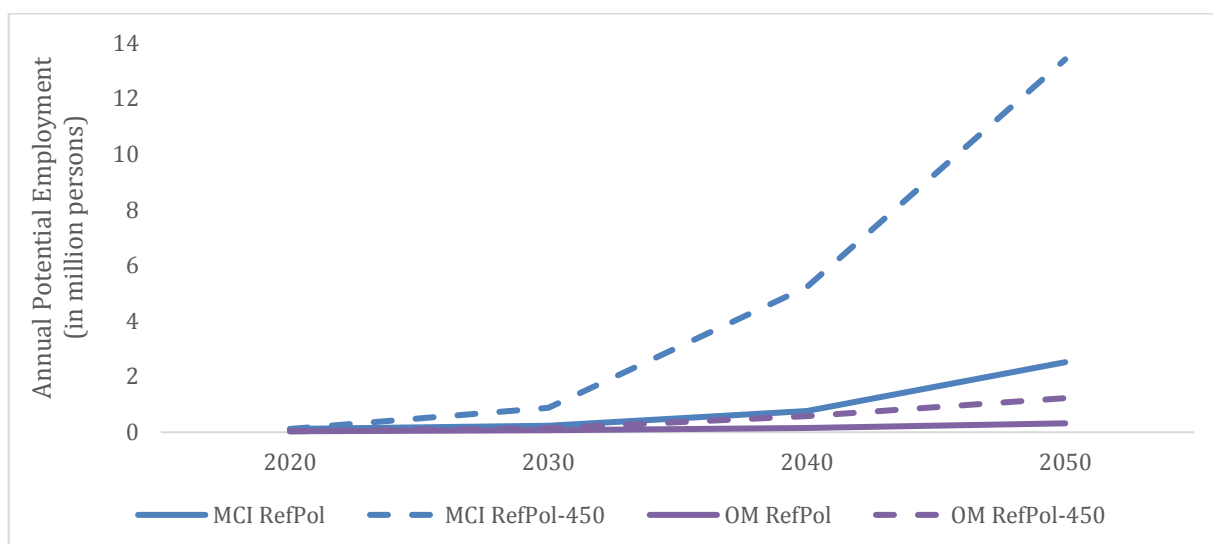


Figure 7: Employment in the electricity sector by activity in SSA, excluding South Africa Source: LIMITS database, Rutovitz & Harris (2012) and own calculations

Figure 8 shows that while employment in fossil fuels is less for the RefPol-450 scenario, the positive employment in nuclear, biomass, hydro, wind, solar, and geothermal completely offsets this. According to the African Development Bank, Africa is well endowed with renewable resources, such as hydropotential generation of about 1,750

TWh and geothermal potential of about 9,000 MW, while “over 80 per cent of the continent receives about 2000 kWh per square meter of solar resources per annum”.³⁸ Countries that have already set targets for renewable energy share include Egypt (20 per cent), Ghana (10 per cent), Madagascar (75 per cent) and South Africa (13 per cent) by 2020, as well as Lesotho (increase by 200MW by 2020), Liberia (30 per cent share of renewable energy in electricity production and 10 per cent overall energy consumption by 2030), Tunisia (reach 3,815MW installed renewable energy capacity by 2030), and Uganda (reach 3,200MW renewable energy capacity by 2030).³⁹

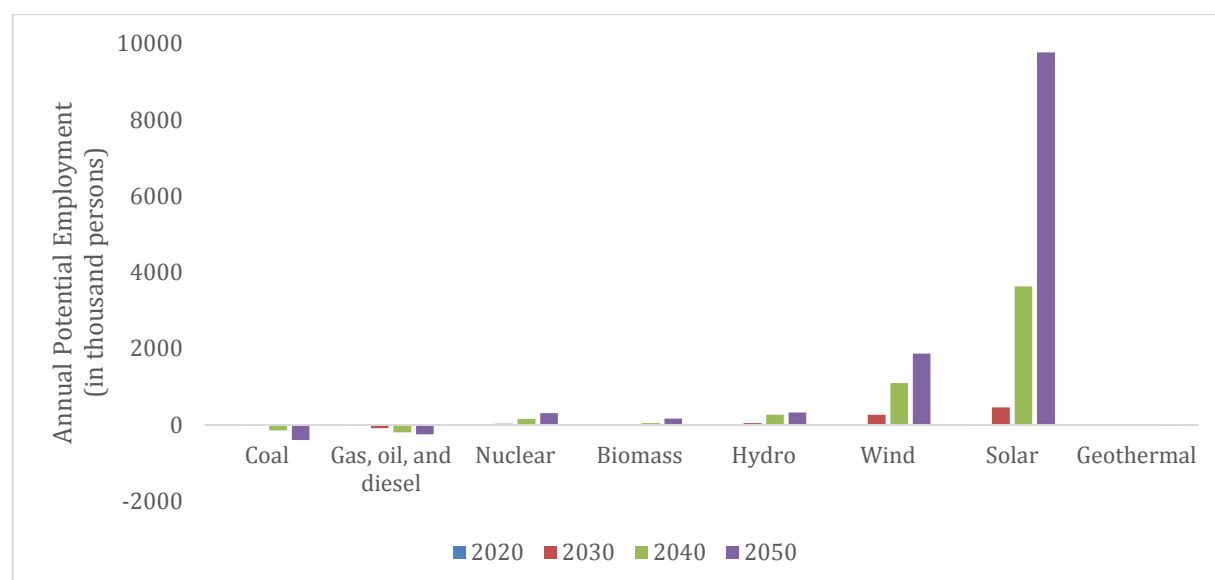


Figure 8: Difference in employment between RefPol and RefPol-450 (positive numbers signifying higher employment for RefPol-450)

Conclusions on employment generation

The net employment in the electricity sector in Africa was analysed in this subsection using an estimation of installed capacity from 2010-2050 by electricity source from the REMIND model and the adjusted employment factor multipliers derived from Rutovitz & Harris (2012). Initial data assessment of employment factors suggests that employment in renewable energy tends to be more labour-intensive, and would still have large room for improvement, given that successive learning provides a higher rate of reduction in employment needed per MW as compared to fossil fuel production. This higher labour requirement in its initial stages provides opportunities for employment creation as early as 2030. Comparing the RefPol and RefPol-450 scenarios, the latter potentially generates an estimated 721 thousand more jobs in 2030 as compared to the former, and as many as 11.8 million more jobs in 2050.

Lower employment possibility for the RefPol scenario is mainly due to its higher volume of consumption of fossil fuels, but much of what will be consumed is imported (reaching 97.2 per cent, 45.1 per cent, 23.2 per cent import dependency for coal, oil and gas, respectively, in 2050, according to the RefPol scenario); hence the larger consumption is not necessarily employment-creating domestically. On the other hand, RefPol-450 introduces an energy mix that has significant increases in renewable energy

³⁸ <http://www.afdb.org/en/blogs/afdb-championing-inclusive-growth-across-africa/post/renewable-energy-in-africa-8829/>.

³⁹ Source: Climate Analytics, Climate Policy Team.

sources, particularly electricity sourced from wind and solar power. Given the increase in capacity development and the relatively more jobs needed for every MW produced, the resulting employment generation is larger, while also creating a more secure source of energy with less import dependency.

Box 9 Opportunities from climate action: Togo case study

By Gilbert Balo, Richard Amegble and Sandra Freitas

Historical climate observations indicate that Togo in general has experienced a progressive increase in temperature, a decline in rainfall and a reduction in the number of rainy days. These trends are likely to have socioeconomic consequences, including impacts on GDP. The clearest example is the agriculture sector, which represents around 30 to 35 per cent of GDP and provides more than 70 per cent of employment. The agriculture sector is directly affected by the deterioration of cultivated land and lack of water, resulting in reduced crop yields and livestock mortality. The advancing sea, resulting from the combination of accelerated coastal erosion, sea-level rise, potentially due to climate change, and the impact of hydroelectric and port infrastructure developments, has also affected the infrastructure sector. For example, the Government was forced twice to change parts of the coastline road of Togo from Lomé to Aného. As sea-level rise continues into the future, important economic activities in coastal zones will be jeopardized by the impacts of climate change. Vital infrastructure services and economic activities in particular are found along the coast and have already suffered major losses due to floods. As part of adaptation strategies to address climate change, seven projects were identified through the National Adaptation Programme of Action (NAPA), three of which are being implemented. However, there is a low level of implementation of adaptation measures, due largely to the lack of financial resources and the low level of initiatives to factor in climate change into national policies and strategies.

A large share of the country's economic output comes from sectors with high sensitivity to climatic conditions. To that end, policymakers need more evidence of not only the severe threats climate change poses to the main economic sectors, but also of the opportunities and co-benefits within the broader economy, associated with the effective implementation of climate action and related investments, and enabling environment for adaptation/mitigation investments. This case study explores the opportunities Togo could anticipate from the implementation of adaptation and mitigation actions and the potential sources and actors of financial mobilization for project implementation. The application of this case study to adaptation investment measures in the context of the NAPA implementation phase could inform the formulation of Togo's national adaptation plan.

Methodological approach

The targeted economic effects assessed in this case study are mainly household welfare, employment (direct and indirect creation/saving) and revenue generated. This case study aims at assessing these co-benefits and exploring the potential contribution of private sector and local actors in adaptation/mitigation financing. The methodological approach used is based on production function maximization and household utility function maximization, subject to budget constraints. To that end,

a model in the context of public investments is developed and extended to take into account private sector investments. For each model developed, the proposed methodology builds on a Ramsey-Cass-Koopmans model (see Uliyanov, 2013) of optimal long-term economic growth, in which inter-temporal choices of household are made. But contrary to Ramsey (1928) and Cass (1965), we are neither considering the optimal saving problem nor postulating full employment in the economy.

Two main periods are considered during which households are playing different roles. The first is the implementation period of projects financed by public/international funds. The second period follows the end of the project implementation period, during which we simulate the production activities based on (1) the willingness of households to pay before consuming public goods, and (2) the Government setting up appropriate policies to enable private sector contribution to implementation costs and annual investment financing in capital stock.

Results

The jobs level for projects that are being implemented by the Government accounted on average for 0.3 per cent of the total number of working population in the service sector per year (other than education, health, accommodation and financial services) and 2.2 per cent in the infrastructure sector per year from 2010 to 2014. The calculation of the number of adaptation/mitigation jobs per unit of investment⁴⁰ shows that EUR 1 million invested would generate on average 1,071 direct jobs in the service sector, up to 1,300 direct jobs in the infrastructure sector and 124 indirect jobs, of which 59 for food and beverage production, 12 in the manufacturing industry and 53 in the service sector.

in production activities. By contrast, the production level increases if the Government introduces an appropriate policy to promote local actors' involvement, which leads to an increase in the jobs level on average at a rate of 3.2 per cent per year from 2016 to 2030. From 2015 to 2030, the projected annual investments in capital stock would contribute to increasing on average the production level for all projects up to 83.6 per cent in the service sector and 63.2 per cent in the infrastructure sector. The required annual investment to maintain this growth rate of job creation/saving and achieve those results represents about 32 per cent of the revenue generated from the project.

Conclusions

Adaptation/mitigation projects implemented by the Government generated direct and indirect jobs from 2010 to 2014. The simulation of local actors' involvement to contribute to financing those projects, based on initial public/international financing, will lead to an increase in jobs at a rate of 3.2 per cent per year from 2016 to 2030, which is faster than the average population growth (2.8 per cent) and therefore could reduce the unemployment rate, everything else remaining equal.

Recommendations

⁴⁰ The calculation is made by dividing the total number of jobs created by public/international investment from 2010 to 2014.

In order to contribute to the work of formulation of NAP processes, the case study provides an overview of opportunities for the Government to build on public/international financing to trigger and maintain private sector involvement in adaptation financing. The outcomes are relevant for Togo, as well as other LDC countries in West Africa which experience comparable climate-change impacts, notably in agriculture and, where relevant, in coastal zones. As a way to mobilize financial resources in order to maintain private sector involvement in the long term, two types of financing have been distinguished: investment in capital stock and project implementation cost. The initial capital stock could be provided by public and international funding sources, whereas the annual investment in capital to be made by the Government could be generated through taxes. Tax collection is a feasible option, if tax policy is perceived as a means of maintaining the growth rate of job creation and saving.

As recommendations based on the findings of this study, the Government could put in place appropriate incentivizing tax policies for the implementation of adaptation and mitigation projects, while mainstreaming climate change policies within the national development plan.

6.2.3 Health benefits of reduced air pollution

One short-term environmental co-benefit of renewable energy deployment is improved air quality, which is good for human health, buildings and ecosystems, as well as agriculture and forestry (Bollen et al., 2009b). Air-quality improvements arise earlier than the effects of GHG emission reductions on limiting climate change (United States Environmental Protection Agency Office of Air and Radiation, 2011).

Pollution from burning fossil fuels is detrimental to human health and is associated with diseases such as acute lower respiratory illness, cerebrovascular disease, ischaemic heart disease and lung cancer (Pope et al., 2002, Burnett et al., 2014). Its main sources are open fires, fossil-fuelled power plants, factories and motor vehicles without appropriate filters. A commonly measured category of air pollutants consists of particles smaller than 2.5 micrometres, referred to as PM_{2.5}.⁴¹ According to some authors (Lelieveld et al., 2015), about 3.3 million people die prematurely every year as a result of anthropogenic PM_{2.5} exposure. The global contribution of PM_{2.5} to premature mortality is expected to increase (Lelieveld et al., 2013). Further health problems caused by climate change arise from natural disasters like extreme heat or floods, which may change infection patterns, for example⁴². However, the avoidance of such impacts is a longer-term direct benefit of mitigation adaptation and is not assessed in this chapter. We assume the long-term global temperature goals as expressed in the Paris Agreement⁴³ of well below 2°C or 1.5°C account for these benefits. Figures 6.9 and 6.10 show the differences in premature deaths in absolute values as well as per 100,000 habitants, between the Reference Policy (RefPol) and 2°C compatible mitigation scenario (RefPol-450) for 2030 and 2050. In the calculations it is assumed that all components of PM_{2.5} (e.g. ammonium sulphate and nitrate) are equally toxic (Lim et al., 2012a). National data for deriving PM_{2.5}-induced premature deaths in 2010, 2030 and 2050 for African countries are used. These data are derived from the energy supply model MESSAGE (Model for Energy Supply Systems and their General

⁴¹ For more information on the worldwide distribution of PM_{2.5} and the World Health Organization's air quality guidelines, see <http://www.epi.yale.edu/visuals/airmap/>.

⁴² For more information, see WHO factsheet at: <http://www.who.int/mediacentre/factsheets/fs266/en/>.

⁴³ <http://unfccc.int/resource/docs/2015/cop21/eng/109r01.pdf>.

Environmental Impact) by down-scaling regional results to the national level. We assume that air quality legislation effective in 2010 prevails up to 2050. The differences between the scenarios become apparent from 2020 onwards, when climate mitigation measures begin to show an effect in the 2°C scenario.

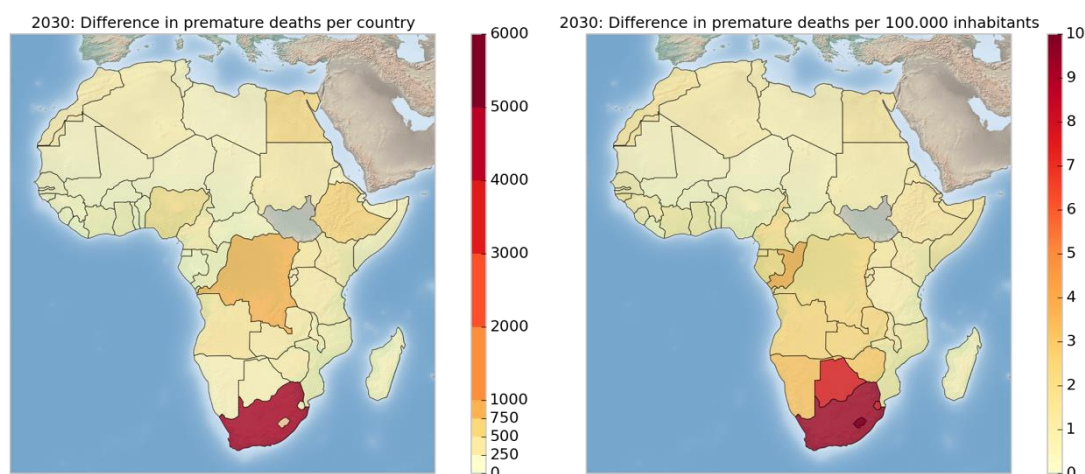


Figure 9 Difference between baseline (RefPol) and 2°C compatible scenario (RefPol-450) in premature deaths in absolute values (left) and per 100,000 habitants (right) caused by PM2.5 in 2030 (no data on South Sudan), Source: MESSAGE model

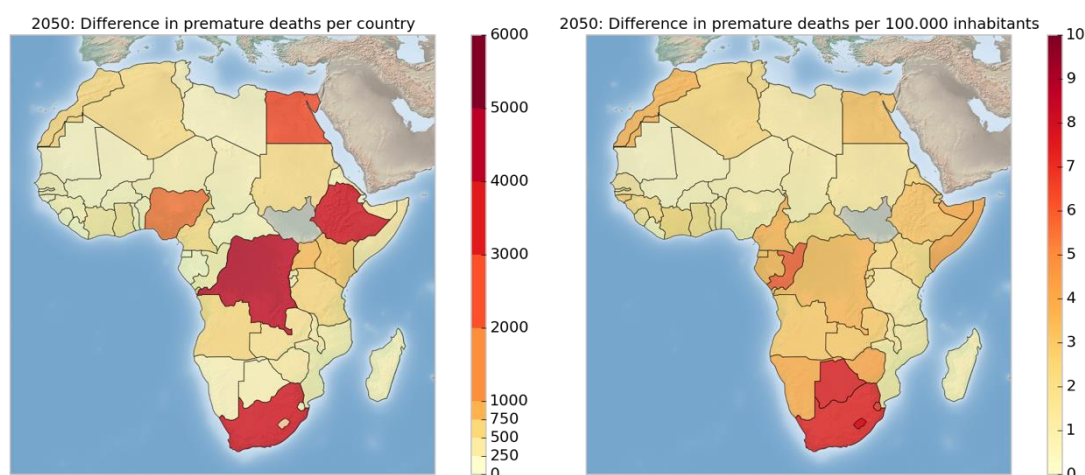


Figure 36 Difference between baseline (RefPol) and 2°C compatible scenario (RefPol-450) in premature deaths in absolute values (left) and per 100,000 habitants (right) caused by PM2.5 in 2050

By 2030, countries in Southern and Central Africa in particular, such as South Africa, Botswana, Angola, Swaziland and the Congo, experience a larger number of premature deaths without additional climate-change mitigation. The effect of climate-change mitigation is more pronounced in 2050, even though general air pollutant levels also decrease in the reference scenario. South Africa, Botswana, the Congo and Morocco, in particular, are large countries that are better off in the scenario with additional climate-change mitigation, but distinct positive effects are apparent for the vast majority of African countries.

The overall picture shows that air pollution-related mortality is decreasing over time and in both scenarios, but fewer deaths occur under the 2°C mitigation scenario. This shows that climate-mitigation policies could provide health benefits across Africa. Despite the massive impacts of outdoor air pollution, indoor emissions from residential energy use like cooking with traditional biomass cause most air-pollution deaths in Africa (Smith et al., 2004), but the use of such fuels is largely phased out under both scenarios.

6.3 Conclusions and policy recommendations

6.3.1 Conclusions

Meeting Africa's energy needs continues to be one of the biggest challenges facing the continent. Currently, about 60 per cent of sub-Saharan Africa has no reliable access to clean and affordable energy sources, especially electricity (AfDB, 2014); and the demand is still projected to grow by 80 per cent in 2040. According to Bazilian et al. (2012), universal electricity access in SSA (excluding South Africa) would require about 374 GW of capacity installed by 2030. That means, they would have to increase the installed capacity by 346 GW in 18 years, starting in 2012.

Energy projections suggest that the rate of growth in demand is much faster than the rate of extraction of fossil fuels; therefore, continued heavy reliance on these sources would only lead to an increase in import dependence, which also make the economy more vulnerable to external disturbances in energy supply and threaten energy security. More sustainable options must be explored in this regard.

In this analysis, we focus on the co-benefits of mitigation, branching from investments in renewable energy and the shift in the energy mix towards the use of more renewable sources of electricity supply and less use of fossil sources. These co-benefits are improved energy security, increased employment potential in the energy sector, and finally, the improvement in health conditions caused by reduced carbon emissions. Results show that the RefPol-450 scenario, which holds the increase in temperature to below 2°C in 2100 through increased mitigation efforts post-2020, reaches a self-sufficiency rate of 104 per cent in 2030, and only slightly decreases in the next decades, reaching a rate of 82 per cent in 2050. These results are much better than the baseline (RefPol) scenario by 26.5 percentage points in 2030, and 44.7 percentage points in 2050. Taking out projected exports from domestic production, the RefPol-450 domestic supply net of exports covers 97 per cent of demand in 2030, or 24.5 percentage points higher than the baseline scenario, and 76 per cent in 2050 or 38.4 percentage points higher. A complementary indicator – import dependency – shows that without mitigation efforts post-2020, a mix that is predominantly coal and gas cannot be supported by local production. Results show that 90.8 per cent of coal consumption would have to be supplied by imports. This number increases to 97.2 per cent in 2050. Gas starts to be imported in 2050 and supplies 23.2 per cent of demand for the energy source. On the contrary, the RefPol-450 scenario presents a decreasing import dependency on coal from 75.7 per cent in 2030 to only 54.2 per cent in 2050.

The interpretation of self-sufficiency, or how much domestic production meets demand, should, however, be treated with caution. While the RefPol-450 scenario allocates investments in energy supply more towards renewable energy, and with amounts that

increase both in level and as a percentage of GDP, unlike the baseline scenario, RefPol-450 also may face higher energy prices due to the possible imposition of carbon tax. This higher price will be likely to decrease demand, which, with an unchanged supply, can improve self-sufficiency indicators.

To aid the analysis and taking into account this possible detrimental effect of higher prices, the report also looks into improvements in energy intensity, a measure of energy efficiency. Results show that, starting in 2030, RefPol-450 experiences a higher level of efficiency compared to the baseline. This improvement is partially attributed to the higher levels of investment in the scenario, among other possibilities.

The shift to energy that can be produced domestically also improves potential employment in the sector, both for activities related to setting up the energy system (MCI) and for its operation and maintenance (OM). Estimates using an installed generation capacity derived from data from LIMITS and the adjusted employment factors for Africa from Rutovitz & Harris, (2012) result in higher potential employment for RefPol-450 as compared to the RefPol scenario by 720.7 thousand in 2030 and as high as 11.8 million more by 2050.

In densely populated areas, renewables will help to reduce premature mortality from air pollution. Several countries are likely to benefit more than others from the improved energy quality. Notably, indoor air quality is an important issue in Africa both in rural areas and cities. A transition to modern cookstoves would reduce the health-related risks.

All co-benefits provide important incentives for the implementation of climate policies in the short term. An improvement in air quality resulting from deployment of renewable energy sources, for example, will provide an immediate co-benefit for the local population.

Additional research is needed to estimate net effects of policies and to quantify second order co-benefits. The Togo case study provides an example of a limited attempt at such an analysis, providing clear lessons and recommendations for a national policy perspective.

6.3.2 Policy recommendations

1. While the costs of mitigation and adaptation are commonly the centrepiece of discussions in climate action, there is also a wide range of opportunities and co-benefits that can be gained by proactively addressing the challenges of climate change. In order to realize these gains, climate action must be initiated and supported by policymakers. A strong political will can ensure efficient planning and effective implementation of policies, reliably coordinated into short- to medium-term plans that can aid the success of climate policies. Having in sight a long-term objective, policies need to remain supported, regardless of political transitions. Based on the results of this report, realizing these gains requires not only external financial and technological support, but also domestic efforts such as:

- (a) Active promotion of renewable energy through tax and investment incentives (financial and administrative in nature), as well as the inclusion of negative externalities of use of fossil fuels in its cost through taxation and elimination of subsidies (where applicable);
 - (b) Increasing awareness on the benefits of using renewable energy in terms of sustainability and access, especially for rural areas, and on the health benefits of avoiding the use of fossil sources;
 - (c) Organizing early preparations to hone the skills of the labour force in building and operating renewable energy systems through capacity-building and knowledge transfers.
- 2. The report supports an increasing amount of investment relative to GDP in order to increase energy efficiency and reach sufficient levels of production to meet the growing energy demand. Apart from investment incentives, alternative funding opportunities must be explored and scaled-up, including non-conventional financial instruments such as guarantees, green bonds, debt swaps and the like.
- 3. In the light of the quantifiable co-benefits, investment decision tools, such as cost-benefit analyses (CBA), must be re-specified to include this wider coverage of benefits and co-benefits, in order to avoid underinvestment of much-needed infrastructures and technologies, and to better inform and enable public and private decision-makers so that they can seize opportunities in adaptation and mitigation policies.

7. Conclusions: a report that fuels the call for economic action

The year 2015 was in many ways exceptional with respect to climate change. First, averaged globally, it was the warmest year ever recorded, about 1°C above the pre-industrial era.⁴⁴ 2015 was also the year of the Paris Conference of the Parties (COP21), where all countries agreed on an ambitious and legally binding agreement to limit and protect against the adverse impacts of climate change.

urgent need to take action on climate change and after more than 20 years of negotiations, 2016 and 2017 mark the beginning of a new era, an era of action and implementation. Information and tools to support policymakers' decisions and actions are however lacking, particularly in African countries. It is hoped that the conclusions of this report, as well as the tools developed for this research, will serve as precursory steps to further enable implementation and action by African countries' economic, financial and development decision-makers.

The conclusions were drawn for each of the chapter of this report, on macroeconomic indicators, development, adaptation and opportunities. This concluding chapter summarizes them, and also investigates them as a possible continuum towards climate-resilient development, assuming that the right decisions are made at the country and international level.

An increasing risk of a low-growth trap

The research conducted for this report employs a new economic model, which better integrates observed and projected climate data as a driver of macroeconomic risk induced by climate variability and climate change on African economies. This novel approach provides three core lessons: first, empirical evidence shows African regions and countries have diverse sensitivity profiles to dry, wet and warm extreme events; second, all African economies are projected to incur severe macroeconomic shocks from climate-related disasters leading to an overall downwards shift of their future macroeconomic development trajectories; third, the divergence in terms of magnitude of macroeconomic impacts between the low- and the high-warming scenarios could occur as early as the 2020s and 2030s, further highlighting the needs for increased pre-2025 and 2030 emission reductions.

Results from the case study conducted in Ethiopia as well as recently published literature show that climate-related disasters could potentially increase pressure on national budgets. In the aftermath of climate-related disasters, government revenues may drop, while expenditures steeply increase, forcing the Government to rely on external debt to fund post-disaster relief and its activities. This chain of consequences could potentially lead to downgrading countries' creditworthiness.

The conclusions of this chapter shed light on two main findings. First, the objective of early mitigation before 2025 and 2030 is crucial to limit climate-change macroeconomic impacts on African economies. Second, economic, development and financial public and private decision-makers would benefit by integrating climate-related risks in their economic forecast tools. This would further facilitate the

⁴⁴ <https://www.wmo.int/media/content/2015-hottest-year-record>.

integration of climate change considerations into development planning, which becomes a prerequisite to mobilize domestic function and access funding from the Green Climate Fund and a necessary step to climate-resilient development.

Mounting adaptation costs and benefits

The report examines the long-term dynamics of damages and adaptation costs in Africa on a large scale. The country case studies show how national and local studies can complement such large-scale assessments in indicating key intervention points and lessons learned.

Looking at the dynamics of damage, the report finds that damage progressively decreases with economic development. As countries develop, they become less dependent on tourism, agriculture and fishery, reducing these impacts in terms of percentage of GDP. Moreover, health impacts are severely reduced through economic growth, as economic growth is found to bring better access to medical care, clean water and improved sanitation.

The difference in damages between the below 2°C world and the above 4°C world is astounding, where gross damages are up to 70 per cent larger in 2050 and 420 per cent in 2100 under high warming as compared to the low-warming scenario. This shows that Africa could be affected by global mitigation efforts to avoid a high-warming world.

Examining adaptation, the most important conclusion is that adaptation benefits greatly outweigh adaptation costs, where benefits are an order of magnitude higher. Adaptation can reduce total impacts by up to 40 per cent. As damages increase, more adaptation is needed, resulting in higher adaptation costs. Furthermore, the ratio of adaptation benefits to costs decreases slightly over time as the most cost-effective adaptation options become exhausted and less cost-effective options are applied, as assumed in the model.

Of course, a continent-wide modelling approach has its limitations, even with the much higher detail and broader data and literature evidence base of the AD-AFRICA model than previous modelling efforts, in particular for Africa. A case study for Morocco for the agriculture sector illustrates how many adaptation options have been developed from the local to the national level and how such options are incorporated in national policies and programmes and hold key lessons for other countries and future policy development cycles. Finally, a case study for Mozambique shows the value of looking far beyond GDP as a measure of the impacts of climate change and benefits of adaptation. Again, on a national and local scale, targeted research shows how vulnerabilities of rural communities can be strengthened through key intervention points.

Opportunities – or the benefits of action

Costs of mitigation and adaptation are commonly the centrepiece when talking about climate action. This report explores the opportunities and co-benefits of proactively addressing the challenges of climate change and keeping temperature increase below 2°C; and, in so doing, also touches on the other side of the coin – the dangers of remaining mute on much-needed climate policy post-2020. Once attention has been

drawn to the benefits, investment decisions that can aid both economic growth and environmental protection in preventing a worsening of climate change can be better supported.

The chapter focuses on the changing availability of resources and opportunities to explore potential sources to sustain growth. Three co-benefits, which are also interrelated with each other, are examined: energy security through a change in energy mix, employment creation through increased investments and expansion of the energy sector, and lastly, health improvements through the use of cleaner energy and a reduction in carbon emissions.

Currently, the lack of a sufficient power infrastructure and the need to meet a growing energy demand are a major challenge for Africa, as about 60 per cent of the population have no reliable access to clean and affordable energy. Renewable energy sources can offer a solution to improve electrification and enhance electricity access, especially in rural areas. Furthermore, African countries now have a unique possibility of leapfrogging: two thirds of the energy-generating capacity needed in 2030 still has to be built.

In a scenario where mitigation policies are implemented in line with the low-warming scenario, Africa's energy self-sufficiency would be about 1.5 times as high by the 2040s and twice as high by the 2050s than in the scenario with no mitigation measures. Moreover, the shift toward more renewable sources in the low-warming scenario lowers the import dependency ratio, which also reduce Africa's vulnerability to external energy supply shocks, such as oil price hikes.

This improvement in local production of energy subsequently improves, not only electricity generation from stable sources, but also employment opportunities in the sector. Results show that potential employment is higher by 0.7 million in 2030 and increasing over time to as high as 11.8 million more in 2050 in the low-warming scenario as compared to the no-mitigation scenario, accounting for manufacturing, construction and installation of the energy system, as well as operations and maintenance-related employment.

Finally, the decline in emissions from the use of clean energy reduces threats to health and mortality, particularly in countries in Southern and Central Africa, notably Angola, Botswana, the Congo, South Africa and Swaziland, whose projected incidence of premature deaths is high without additional climate-change mitigation.

The findings suggest the advantages for policymakers to foster ambitious mitigation and adaptation actions in African countries. The main recommendation is to structurally include ex-ante and ex-post analysis of cross-cutting opportunities and co-benefits in the assessment of policies and projects, which could become a prerequisite to countries' investments and planning policies.

Impacts, policies and benefits as an economic continuum

The report explores in a sequence the macroeconomic consequences of climate change, consequences for multidimensional development, the costs and benefits of adaptation and finally the opportunities and co-benefits arising from climate action. However, this

sequence of consequences and effects needs to be analysed as a continuum, which outcome depends on policies and strategies being undertaken by policymakers.

It appears that not tackling climate change in development and poverty eradication planning may lead to severe negative consequences, significantly shifting downwards African countries' development trajectories. In this context, African policymakers could seize opportunities for action to avoid such consequences for their economies. Efforts to address these consequences are projected to entail very high costs for African countries' economies, which need to be supported by developed countries, domestic mobilization and innovative sources of financing.

As explained in the report, climate change is projected to change the frequency and intensity of climate-related disasters, as well as further push future climate outside of what is "normal" at present. Through the interplay of climate-economy sensitivity, this report finds that climate change could have detrimental consequences for government budget and macroeconomic indicators. However, the higher the level of development, the lower the sensitivity of the overall economy. By altering countries' development trajectory, climate may therefore limit their ability to reduce their sensitivity. This interconnection between increasing intensity of climate-related disasters, sensitivity and macroeconomic development could potentially lead to a downwards development spiral or a macroeconomic low-growth and poverty trap.

Policy actions at the national and international level can circumvent these negative consequences. An increasing effort towards reducing GHG emissions at the global level would significantly contribute to reducing the negative consequences of climate-related disasters and change and subsequently lower the negative impacts on development. In addition to reducing the impacts of climate change, mitigation would also yield meaningful co-benefits, such as job creation, reduction in air pollution and improved energy security leading to an improvement in economic and human development conditions. Adaptation to the impacts of climate change will contribute to reducing countries' sensitivity and would also generate co-benefits such as job creation and increased adaptive capacity.

Providing African countries' decision-makers with adequate information on climate change-induced risks could support them in engaging development and poverty eradication development planning processes that integrate climate change considerations. In the absence of effective actions undertaken, African countries may face an increasing risk of macroeconomic low-growth and poverty traps. However, policymakers and countries enabled through international support and adequate domestic resource mobilization to implement policies and actions will be rewarded by remarkable benefits.

References

- Abidoye, B. O., & Odusola, A. F. (2015). Climate change and economic growth in Africa: An econometric analysis. *Journal of African Economies*, 25(1), 1–25. <https://doi.org/10.1093/jae/eju033>
- Addison, T. (2015). *Thirty years in Africa's development From structural adjustment to structural transformation?* (WIDER Working Paper No. 2015/119 Thirty). Helsinki, Finland.
- Adhikari, U., Nejadhashemi, A. P., & Woznicki, S. A. (2015). Climate change and eastern Africa: a review of impact on major crops. *Food and Energy Security*, 4(2), 110–132.
- AfDB. (2014). *Development Effectiveness Review 2014 Thematic review – Energy*.
- African Development Bank. (2011). *Africa in 50 Years' Time – The Road Towards Inclusive Growth*. Tunis, Tunisia.
- Agnew, M. D., & Viner, D. (2001). Potential impacts of climate change on international tourism. *Tourism and Hospitality Research*, 3(1), 37–60.
- Allison, E. H., Perry, A. L., Badjeck, M.-C., Neil Adger, W., Brown, K., Conway, D., ... Dulvy, N. K. (2009). Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries*, 10(2), 173–196. <https://doi.org/10.1111/j.1467-2979.2008.00310.x>
- Barrios, S., Bertinelli, L., & Strobl, E. (2010). Trends in rainfall and economic growth in Africa: A neglected cause of the African growth tragedy. *Review of Economics and Statistics*, 92(2), 350–366.
- Bazilian, M., Nussbaumer, P., Rogner, H. H., Brew-Hammond, A., Foster, V., Pachauri, S., ... Kammen, D. M. (2012). Energy access scenarios to 2030 for the power sector in sub-Saharan Africa. *Utilities Policy*, 20(1), 1–16. <https://doi.org/10.1016/j.jup.2011.11.002>
- Ben Mohamed, A. (2010). Climate change risks in Sahelian Africa. *Regional Environmental Change*, 11(S1), 109–117. <https://doi.org/10.1007/s10113-010-0172-y>
- Benson, C., & Clay, E. J. (2004). *Understanding the Economic and Financial Impacts of Natural Disasters* (Disaster R). Washington, D.C.: International Bank for Reconstruction and Development / World Bank.
- Berg, E. (1976). *The Economic Impact of Drought and Inflation in the Sahel* (No. 51). Discussion paper. Ann Arbor, MI.
- Bezabih, M., Di Falco, S., & Mekonnen, A. (2014). *Is it the climate or the weather? Differential economic impacts of climatic factors in Ethiopia* (No. 148). London, UK.
- Bhave, A. G., Conway, D., Dessai, S., & Stainforth, D. A. (2016). Barriers and opportunities for robust decision making approaches to support climate change adaptation in the developing world. *Climate Risk Management*, 14, 1–10. <https://doi.org/10.1016/j.crm.2016.09.004>
- Bollen, J., Guay, B., & Corfee-Morlot, J. (2009a). *Co-benefits of climate change mitigation policies: Literature review and new results*.
- Bollen, J., Guay, B., & Corfee-Morlot, J. (2009b). *Co-benefits of climate change*

mitigation policies: Literature review and new results.

- Brown, C., Meeks, R., Ghile, Y., & Hunu, K. (2013). Is water security necessary ? An empirical analysis of the effects of climate hazards on national-level economic growth. *Philosophical Transactions of the Royal Society*, (371), 1–19. Retrieved from <http://rsta.royalsocietypublishing.org/content/371/2002/20120416.abstract>
- Brown, C., Meeks, R., Hunu, K., & Yu, W. (2010). Hydroclimate risk to economic growth in sub-Saharan Africa. *Climatic Change*, 106(4), 621–647. <https://doi.org/10.1007/s10584-010-9956-9>
- Burke, M., Hsiang, S. M., & Miguel, E. (2015). Global non-linear effect of temperature on economic production. *Nature*, (1), 1–16. <https://doi.org/10.1038/nature15725>
- Burnett, R. T., Pope, C. Arden, I., Ezzati, M., Olives, C., Lim, S. S., Mehta, S., ... Cohen, A. (2014). An Integrated Risk Function for Estimating the Global Burden of Disease Attributable to Ambient Fine Particulate Matter Exposure. *Environmental Health Perspectives*. <https://doi.org/10.1289/ehp.1307049>
- Calzadilla, A., Zhu, T., Rehdanz, K., Tol, R. S. J., & Ringler, C. (2013). Economywide impacts of climate change on agriculture in Sub-Saharan Africa. *Ecological Economics*, 93, 150–165.
- CCAFS East Africa. (2015). Kenya integrates climate-smart agriculture into its Intended Nationally Determined Contribution. Retrieved from https://ccafs.cgiar.org/blog/kenya-integrates-climate-smart-agriculture-its-intended-nationally-determined-contribution?utm_content=buffer28595&utm_medium=social&utm_source=linkedin.com&utm_campaign=buffer#.VhzX3aK1y8T
- Cheung, W. W. L., Lam, V. W. Y., Sarmiento, J. L., Kearney, K., Watson, R., Zeller, D., & Pauly, D. (2010). Large-scale redistribution of maximum fisheries catch potential in the global ocean under climate change. *Global Change Biology*, 16(1), 24–35. <https://doi.org/10.1111/j.1365-2486.2009.01995.x>
- Chinowsky, P., Hayles, C., Schweikert, A., Strzepek, N., Strzepek, K., & Schlosser, C. A. (2011). Climate change: comparative impact on developing and developed countries. *The Engineering Project Organization Journal*, 1(1), 67–80.
- Chinowsky, P., Schweikert, A., Strzepek, N., Manahan, K., & Strzepek, K. (2011). *Adaptation advantage to climate change impacts on road infrastructure in Africa through 2100*. Working paper//World Institute for Development Economics Research.
- CRED. (2017). *EM-DAT: The OFDA/CRED International Disaster Database*. Louvain, Belgium. Retrieved from <http://emdat.be/>
- Cunado, J., & Ferreira, S. (2014). The Macroeconomic Impacts of Natural Disasters : The Case of Floods. *Land Economics*, 90(1), 149–168.
- Dasgupta, S., Laplante, B., Murray, S., & Wheeler, D. (2011). Exposure of developing countries to sea-level rise and storm surges. *Climatic Change*, 106(4), 567–579. <https://doi.org/10.1007/s10584-010-9959-6>
- de Bruin, K. C., Dellink, R. B., & Tol, R. S. J. (2009). AD-DICE: an implementation of adaptation in the DICE model. *Climatic Change*, 95(1–2), 63–81. <https://doi.org/10.1007/s10584-008-9535-5>
- de Bruin, K., Dellink, R., & Agrawala, S. (2009). *Economic Aspects of Adaptation to*

- Climate Change* (OECD Environment Working Papers No. 6). Paris, France. Retrieved from <http://www.oecd-ilibrary.org/content/workingpaper/225282538105>
- Dell, M., Jones, B. F., & Olken, B. A. (2012a). Temperature Shocks and Economic Growth: Evidence from the Last Half Century. *American Economic Journal: Macroeconomics*, 4(3), 66–95. <https://doi.org/10.1257/mac.4.3.66>
- Dell, M., Jones, B. F., & Olken, B. A. (2012b). Web Appendix: Temperature Shocks and Economic Growth. *American Economic Journal: Macroeconomics*, 4(3), 1–62.
- Dell, M., Jones, B. F., & Olken, B. A. (2013). *What Do We Learn from the Weather? The New Climate-Economy Literature (Appendix)* (No. 19578). Cambridge, MA.
- Dellink, R., Chateau, J., Lanzi, E., & Magné, B. (2015). Long-term economic growth projections in the Shared Socioeconomic Pathways. *Global Environmental Change*, 1–15. <https://doi.org/10.1016/j.gloenvcha.2015.06.004>
- Du, D., Zhao, X., & Huang, R. (2017). The impact of climate change on developed economies. *Economic Letters*. <https://doi.org/10.1111/j.1574-0862.2009.00379.x>
- Ebi, K. L. (2008). Adaptation costs for climate change-related cases of diarrhoeal disease, malnutrition, and malaria in 2030. *Globalization and Health*, 4(1), 1–9.
- Escaleras, M., & Register, C. A. (2011). Natural Disasters and Foreign Direct Investment. *Land Economics*, 87(May), 346–363.
- Fankhauser, S., & McDermott, T. K. J. (2014). Understanding the adaptation deficit: Why are poor countries more vulnerable to climate events than rich countries? *Global Environmental Change*, 27, 9–18. <https://doi.org/http://dx.doi.org/10.1016/j.gloenvcha.2014.04.014>
- Felbermayr, G., & Gröschl, J. (2013). *Naturally Negative: The Growth Effects of Natural Disasters* (Category 6: Fiscal Policy, Macroeconomic and Growth No. 4439). Munich, Germany.
- Ferroukhi, R., Lucas, H., Renner, M., Lehr, U., Breitschopf, B., Lallement, D., & Petrick, K. (2015). *Renewable Energy and Jobs – Annual Review 2015*.
- Fischer, G. (2009). World food and agriculture to 2030/50: How do climate, change and bioenergy alter the long-term outlook for food, agriculture and resource availability? Expert meeting on How to feed the World in 2050 (12-13 October 2009) FAO, Rome, Italy FAO.
- Foster, V., & Briceño-Garmendia, C. M. (Eds.). (2009). *Africa's Infrastructure*. The World Bank. <https://doi.org/10.1596/978-0-8213-8041-3>
- Funk, C., Dettinger, M. D., Michaelsen, J. C., Verdin, J. P., Brown, M. E., Barlow, M., & Hoell, A. (2008). Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. *Proceedings of the National Academy of Science*, 105(32), 11081–11086.
- Galbraith, R. M., PRICE, D. J., Shackman, L., & others. (2005). *Scottish road network climate change study*.
- Gebrehiwot, T., & van der Veen, A. (2013). Climate change vulnerability in Ethiopia: disaggregation of Tigray Region. *Journal of Eastern African Studies*, 7(4), 607–629. <https://doi.org/10.1080/17531055.2013.817162>

- Giannakopoulos, C., Le Sager, P., Bindi, M., Moriondo, M., Kostopoulou, E., & Goodess, C. M. (2009). Climatic changes and associated impacts in the Mediterranean resulting from a 2 °C global warming. *Global and Planetary Change*, 68(3), 209–224. <https://doi.org/10.1016/j.gloplacha.2009.06.001>
- Giannini, A., Saravanan, R., & Chang, P. (2003). Oceanic Forcing of Sahel Rainfall on Interannual to Interdecadal Time Scales. *Science*, 302(2), 1027–1030. [https://doi.org/10.1016/S1364-8152\(03\)00114-2](https://doi.org/10.1016/S1364-8152(03)00114-2)
- Hallegatte, S. (2015). *The Indirect Cost of Natural Disasters and an Economic Definition of Macroeconomic Resilience* (No. 7357). *Policy Research Working Papers*. Washington, D.C. Retrieved from [https://www.gfdrr.org/sites/gfdrr.org/files/documents/Public finance and macroeconomics, Paper 3.pdf](https://www.gfdrr.org/sites/gfdrr.org/files/documents/Public%20finance%20and%20macroeconomics,%20Paper%203.pdf)
- Hallegatte, S., & Dumas, P. (2009). Can natural disasters have positive consequences? Investigating the role of embodied technical change. *Ecological Economics*, 68(3), 777–786. <https://doi.org/10.1016/j.ecolecon.2008.06.011>
- Hallegatte, S., Hourcade, J.-C., & Ambrosi, P. (2007). Using climate analogues for assessing climate change economic impacts in urban areas. *Climatic Change*, 82(1–2), 47–60. <https://doi.org/10.1007/s10584-006-9161-z>
- Hallegatte, S., & Przyluski, V. (2010). *The Economics of Natural Disasters: Concepts and Methods* (Policy Research Working Paper No. 5507). Washington, DC.
- Hamilton, J. M., Maddison, D. J., & Tol, R. S. J. (2005). Effects of climate change on international tourism. *Climate Research*, 29(3), 245–254.
- Heal, G., & Park, J. (2013). *Feeling the Heat: Temperature, Physiologie and the Wealth of Nations* (NBER Working Paper Series No. 19725). Cambridge, MA.
- Hempel, S., Frieler, K., Warszawski, L., Schewe, J., & Piontek, F. (2013). A trend-preserving bias correction: the ISI-MIP approach. *Earth System Dynamics*, 4(2), 219–236. <https://doi.org/10.5194/esd-4-219-2013>
- Hinkel, J., Brown, S., Exner, L., Nicholls, R. J., Vafeidis, A. T., & Kebede, A. S. (2012). Sea-level rise impacts on Africa and the effects of mitigation and adaptation: an application of DIVA. *Regional Environmental Change*, 12(1), 207–224. <https://doi.org/10.1007/s10113-011-0249-2>
- Hoerling, M., Eischeid, J., Perlwitz, J., Quan, X., Zhang, T., & Pegen, P. (2012). On the Increased Frequency of Mediterranean Drought. *Journal of Climate*, 25(6), 2146–2161. <https://doi.org/10.1175/JCLI-D-11-00296.1>
- IEA. (2014). *Africa Energy Outlook*.
- IEA; OECD. (2014). *Africa Energy Outlook – A focus on energy prospects in Sub-Saharan Africa*.
- IMF. (2003). *Fund Assistance for Countries Facing Exogenous Shocks*.
- International Energy Agency. (2014). *World Energy Investment Outlook – Special Report*. International Energy Agency, Paris, France (Vol. 23). <https://doi.org/10.1049/ep.1977.0180>
- IPCC. (2012). *Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)*. Geneva, Switzerland. Retrieved from <http://ipcc-wg2.gov/SREX/report/>

- IPCC. (2014a). Summary for Policymakers, In: Climate Change 2014, Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
- IPCC. (2014b). Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. *Environmental Science and Pollution Research*, 3(1), 52–57. <https://doi.org/10.1007/BF02986817>
- IRENA. (2012a). *Prospects for the African power sector – Scenarios and strategies for Africa Project*.
- IRENA. (2012b). *Prospects for the African power sector – Scenarios and strategies for Africa Project*.
- Kirshen, P. (2007). Adaptation Options and Cost in Water Supply.
- Klein R.J.T., Midgley, G. F., Preston, B. L., Alam, M., Berkhout, F. G. H., Dow, K., & Shaw, M. R. (2014). 16. *Adaptation Opportunities, Constraints, and Limits. Assessment Report 5- Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects*.
- Knox, J., Hess, T., Daccache, A., & Wheeler, T. (2012). Climate change impacts on crop productivity in Africa and South Asia. *Environmental Research Letters*, 7(3), 34032.
- Kocornik-Mina, A., & Fankhauser, S. (2015). *Climate change adaptation in dynamic economies: The cases of Colombia and West Bengal*. London, UK.
- Kraemer, M., Msrnik, M., Petrov, A., & Glass, B. (2015). *Storm Alert : Natural Disasters Can Damage Sovereign Creditworthiness*.
- Kriegler, E., Tavoni, M., Aboumahboub, T., Luderer, G., Calvin, K., DeMaere, G., ... van Vuuren, D. P. (2014a). What Does the 2 C Target Imply for a Global Climate Agreement in 2020. *Climate Change Economics*, 4. <https://doi.org/10.1142/S2010007813400083>
- Lagarde, C. (2014). Africa Rising—Building to the Future. Maputo, Mozambique: IMF. Retrieved from <http://www.imf.org/external/np/speeches/2014/052914.htm>
- Lalthapersad-Pillay, P., & Udjo, E. (2014). The Implications of Climate Change for Africa's Economic Development. *Journal of Economic and Financial Sciences*, 7(October 2014), 869–886.
- Lam, V. W. Y., Cheung, W. W. L., Swartz, W., & Sumaila, U. R. (2012). Climate Change Impacts on Fisheries in West Africa : Implications for Economic, Food and Nutritional Security. *African Journal of Marine Science*, 34(1), 37–41.
- Lelieveld, J., Evans, J. S., Fnais, M., Giannadaki, D., & Pozzer, A. (2015). The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature*, 525(7569), 367–71. <https://doi.org/10.1038/nature15371>
- Lelieveld, J., Hadjinicolaou, P., Kostopoulou, E., Giannakopoulos, C., Pozzer, A., Tanarhte, M., & Tyrlis, E. (2013). Model projected heat extremes and air pollution in the eastern Mediterranean and Middle East in the twenty-first century. *Regional Environmental Change*, 1–13. <https://doi.org/10.1007/s10113-013-0444-4>
- Lim, S. S., Vos, T., Flaxman, A. D., Danaei, G., Shibuya, K., Adair-Rohani, H., ... Ezzati, M. (2012a). A comparative risk assessment of burden of disease and injury

- attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet*, 380(9859), 2224–2260. [https://doi.org/10.1016/S0140-6736\(12\)61766-8](https://doi.org/10.1016/S0140-6736(12)61766-8)
- Lim, S. S., Vos, T., Flaxman, A. D., Danaei, G., Shibuya, K., Adair-Rohani, H., ... Ezzati, M. (2012b). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The Lancet*, 380(9859), 2224–2260. [https://doi.org/10.1016/S0140-6736\(12\)61766-8](https://doi.org/10.1016/S0140-6736(12)61766-8)
- LIMITS. (2013). LIMITS Data Base. Retrieved from <https://tntcat.iiasa.ac.at/LIMITSDB/dsd?Action=htmlpage&page=about>
- Lucas, P. L., Nielsen, J., Calvin, K., McCollum, D. L., Marangoni, G., Strefler, J., ... van Vuuren, D. P. (2015). Future energy system challenges for Africa: Insights from Integrated Assessment Models. *Energy Policy*, 86, 705–717. <https://doi.org/10.1016/j.enpol.2015.08.017>
- Lyon, B., & Barnston, A. G. (2005). ENSO and the Spatial Extent of Interannual Precipitation Extremes in Tropical Land. *Journal of Climate*, (1998), 5095–5109.
- McKee, T. B., Doesken, N. J., & Kleist, J. (1993). The relationship of drought frequency and duration to time scales. In *Eight Conferences on Applied Climatology* (pp. 179–184). Anaheim, California: American Meteorological Society.
- McMillian, M. S., & Rodrik, D. (2013). *Globalization, Structural Change and Productivity Growth* (NBER Working Paper Series No. 17143). Cambridge, MA. <https://doi.org/10.1017/CBO9781107415324.004>
- Mendelsohn, R., Dinar, A., & Sanghi, A. (2001). The effect of development on the climate sensitivity of agriculture. *Environment and Development Economics*, null(1), 85–101. <https://doi.org/null>
- Müller, C., Waha, K., Bondeau, A., & Heinke, J. (2014). Hotspots of climate change impacts in sub-Saharan Africa and implications for adaptation and development. *Global Change Biology*, n/a-n/a. <https://doi.org/10.1111/gcb.12586>
- Nordhaus, W. D. (2010). Economic aspects of global warming in a post-Copenhagen environment. *Proceedings of the National Academy of Sciences*, 107(26), 11721–11726.
- Nordhaus, W. D. (2010). Projections of Sea Level Rise (SLR).
- O'Neill, B. C., Kriegler, E., Ebi, K. L., Kemp-Benedict, E., Riahi, K., Rothman, D. S., ... Solecki, W. (2015). The roads ahead: Narratives for shared socioeconomic pathways describing world futures in the 21st century. *Global Environmental Change*, 1–12. <https://doi.org/10.1016/j.gloenvcha.2015.01.004>
- Pachauri, R. K., Myles, A. R., Barros, V. C., & Broome, J. et al. (2014). *CLIMATE CHANGE 2014 Synthesis Report Summary for Policymakers*.
- Parry, M. L., Canziani, O. F., Palutikof, J. P., der Linden, P. J., & Hanson, C. E. (2007). Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change, 2007. *Climate Change 2007: Working Group II: Impacts, Adaptation and Vulnerability*.
- Pettersson, T., & Wallensteen, P. (2015). Armed Conflicts, 1946-2014. *Journal of Peace Research*, 52(4).

- Pope, C. A., Burnett, R. T., Thun, M. J., Calle, E. E., Krewski, D., Ito, K., & Thurston, G. D. (2002). Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution. *JAMA: The Journal of the American Medical Association*, 287(9), 1132–1141. <https://doi.org/10.1016/j.scitotenv.2011.03.017>
- Porter, J. R., Liyong, X., Challinor, A., Cochrane, K., Howden, M., Iqbal, M. M., ... Travasso, M. I. (2014). Chapter 7: food security and food production systems. IPCC 2014: climate change 2014: impacts, adaptation, and vulnerability. Contribution of working group II to the fifth assessment report of the Intergovernmental Panel on Climate Change. Final draft. IP. Cambridge University Press, Cambridge.
- Rao, S., Pachauri, S., Dentener, F., Kinney, P., Klimont, Z., Riahi, K., & Schoepp, W. (2013). Better air for better health: Forging synergies in policies for energy access, climate change and air pollution. *Global Environmental Change*, 23(5), 1122–1130. <https://doi.org/10.1016/j.gloenvcha.2013.05.003>
- Raworth, K. (2007). Adapting to Climate Change: What's needed in poor countries, and who should pay. *Oxfam Policy and Practice: Climate Change and Resilience*, 3(1), 42–88.
- Reilly, J. M., & Schimmelpfennig, D. (1999). Agricultural impact assessment, vulnerability, and the scope for adaptation. *Climatic Change*, 43(4), 745–788.
- Ringler, C., Zhu, T., Cai, X., Koo, J., & Wang, D. (2010). Climate change impacts on food security in sub-Saharan Africa. *Insights from Comprehensive Climate Change Scenarios*.
- Rodrik, D. (2013). *Structural Change, Fundamentals, and Growth: An Overview*. Cambridge, MA. Retrieved from http://drodrik.scholar.harvard.edu/files/dani-rodrik/files/structural-change-fundamentals-and-growth-an-overview_revised.pdf?m=1435004204
- Rohde, R., Muller, R., Jacobsen, R., Perlmutter, S., Rosenfeld, A., Wurtele, J., ... Mosher, S. (2013). Berkeley Earth Temperature Averaging Process. *Geoinformatics & Geostatistics: An Overview*. Retrieved from http://www.scitechnol.com/berkeley-earth-temperature-averaging-process-IpUG.php&&article_id=582
- Rutovitz, J., & Harris, S. (2012). Calculating global energy sector jobs: 2012 methodology. *Prepared for Greenpeace International by the Institute for Sustainable Futures, University of Technology, Sydney.*, (June). Retrieved from <http://cfsites1.uts.edu.au/find/isf/publications/rutovitzharris2012globalenergyjobsmethycalc.pdf>
- Sauerborn, R., Kjellstrom, T., & Nilsson, M. (2009). Health as a crucial driver for climate policy. *Global Health Action*, 2(0), 1–5. <https://doi.org/10.3402/gha.v2i0.2104>
- Schaeffer, M., Baarsch, F., Adams, S., De Bruin, K., de Marez, L., Freitas, S., ... Hare, B. (2013). *Africas Adaptation Gap*. Retrieved from <http://www.unep.org/pdf/AfricaAdapataionGapreport.pdf>
- Schaeffer, M., Baarsch, F., Adams, S., de Bruin Kelly Freitas, S., Hof, A., & Hare, B. (2013). Africa's Adaptation. United Nations Environment Programme(UNEP).
- Schaeffer, M., Baarsch, F., Charles, L., De Bruin, K., Hare, B., Hof, A., & Mace, M. (2014). *Loss and Damage in Africa*. Addis Ababa, Ethiopia.

- Schellnhuber, H.-J., Hare, B., Serdeczny, O., Schaeffer, M., Adams, S., Baarsch, F., ... Rocha, M. (2013). *Turn Down The Heat: Climate Extremes, Regional Impacts and the Case for Resilience*. Washington, D.C.: A report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics, World Bank.
- Schellnhuber, H.-J., Hare, W. L., Serdeczny, O., Adams, S., Coumou, D., Frieler, K., ... Warszawski, L. (2012). *Turn Down the Heat: Why a 4°C Warmer World Must be Avoided*. Washington DC: A report for the World Bank by the Potsdam Institute for Climate Impact Research and Climate Analytics, World Bank.
- Schellnhuber, H. J., Hare, B., Serdeczny, O., Schaeffer, M., Adams, S., Baarsch, F., ... Rocha, M. (2013). *Turn down the heat : climate extremes, regional impacts, and the case for resilience*. Washington, D.C. Retrieved from <http://documents.worldbank.org/curated/en/2013/06/17862361/turn-down-heat-climate-extremes-regional-impacts-case-resilience-full-report>
- Schellnhuber, H. J., Reyer, C., Hare, B., Waha, K., Otto, I. M., Serdeczny, O., ... Thonicke, K. (2014). *Turn Down the Heat: Confronting the New Climate Normal*. Washington DC: The World Bank.
- Schlenker, W., & Roberts, M. J. (2009). Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change. *Proceedings of the National Academy of Sciences of the United States of America*, 106(37), 15594–15598. <https://doi.org/10.1073/pnas.0906865106>
- Schneider, U., Becker, A., Finger, P., Meyer-Christoffer, A., Rudolf, B., & Ziese, M. (2011). GPCC Full Data Reanalysis Version 6.0 at 0.5°: Monthly Land-Surface Precipitation from Rain-Gauges built on GTS-based and Historic Data. https://doi.org/10.5676/DWD_GPCC/FD_M_V6_050
- Shabnam, N. (2014). Natural Disasters and Economic Growth: A Review. *International Journal of Disaster Risk Science*, 5(2), 157–163. <https://doi.org/10.1007/s13753-014-0022-5>
- Sillmann, J., Kharin, V. V., Zwiers, F. W., Zhang, X., & Bronaugh, D. (2013). Climate extreme indices in the CMIP5 multi-model ensemble. Part 2: Future climate projections. *Journal of Geophysical Research, Atmospheres*. <https://doi.org/10.1002/jgrd.50188>
- Smith, K. R., Mehta, S., & Maeusezahl-Feuz, M. (2004). “Indoor air pollution from household use of solid fuels.” *Comparative Quantification of Health Risks*. <https://doi.org/10.1078/1438-4639-00224>
- Stern, N. (2006). *Stern Review: The Economics of Climate Change*. London, UK. Retrieved from http://mudancasclimaticas.cptec.inpe.br/~rmclima/pdfs/destaques/sternreview_report_complete.pdf
- Stern, N. (2013). The Structure of Economic Modeling of the Potential Impacts of Climate Change: Grafting Gross Underestimation of Risk onto Already Narrow Science Models. *Journal of Economic Literature*, 51(3), 838–859.
- Szabó, S., Bódis, K., Huld, T., & Moner-Girona, M. (2011). Energy solutions in rural Africa: mapping electrification costs of distributed solar and diesel generation versus grid extension. *Environmental Research Letters*, 6(3), 34002. <https://doi.org/10.1088/1748-9326/6/3/034002>

- Tan, G., & Shibasaki, R. (2003). Global estimation of crop productivity and the impacts of global warming by GIS and EPIC integration. *Ecological Modelling*, 168(3), 357–370.
- Tatsumi, K., Yamashiki, Y., da Silva, R., Takara, K., Matsuoka, Y., Takahashi, K., ... Kawahara, N. (2011). Estimation of potential changes in cereals production under climate change scenarios. *Hydrological Processes*, 25(17), 2715–2725.
- Thornton, P. K., Jones, P. G., Ericksen, P. J., & Challinor, A. J. (2011). Agriculture and food systems in sub-Saharan Africa in a 4°C+ world. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences*, 369(1934), 117–36. <https://doi.org/10.1098/rsta.2010.0246>
- Tol, R. S. J. (2002). Estimates of the damage costs of climate change, Part II. Dynamic estimates. *Environmental and Resource Economics*, 21(2), 135–160.
- Tol, R. S. J. (2008). Climate, development and malaria: an application of FUND. *Climatic Change*, 88(1), 21–34.
- Twerefou, D. K., Chinowsky, P., Adjei-Mantey, K., & Strzepek, N. L. (2015). The Economic Impact of Climate Change on Road Infrastructure in Ghana. *Sustainability*, 7(9), 11949–11966.
- U.S. Environmental Protection Agency Office of Air and Radiation. (2011). *The Benefits and Costs of the Clean Air Act from 1990 to 2020*.
- UNDP. (2007). *Human development report 2007/2008: Fighting climate change: human solidarity in a divided world*. Oxford University Press for UNDP.
- UNECA. (2015). *MDG Report 2015: Assessing Progress in Africa toward the Millennium Development Goals*. <https://doi.org/10.1017/9781107301110> accessed 26 July 2015
- UNEP. (2015). *The Emissions Gap Report 2015. A UNEP Synthesis Report*. United Nations Environment Programme (UNEP).
- UNFCCC. (2007). *Investment and Financial Flows to Address Climate Change. UNFCCC, Bonn, Germany*.
- Vicente-Serrano, S. M., & López-Moreno, J. I. (2005). Hydrological response to different time scales of climatological drought: an evaluation of the Standardized Precipitation Index in a mountainous Mediterranean basin. *Hydrology and Earth System Sciences*, 9(5), 523–533. Retrieved from <http://www.hydrol-earth-syst-sci.net/9/523/2005/hess-9-523-2005.html>
- Vizy, E. K., & Cook, K. H. (2012). Mid-twenty-first-century changes in extreme events over northern and tropical Africa. *Journal of Climate*, 25, 5748–5767. <https://doi.org/10.1175/JCLI-D-11-00693.1>
- Warszawski, L., Frieler, K., Huber, V., Piontek, F., Serdeczny, O., & Schewe, J. (2014). The Inter-Sectoral Impact Model Intercomparison Project (ISI-MIP): project framework. *Proceedings of the National Academy of Sciences of the United States of America*, 111(9), 3228–32. <https://doi.org/10.1073/pnas.1312330110>
- WEIO. (2014). WEIO- Investment Costs – Power generation. Retrieved from <http://www.worldenergyoutlook.org/weomodel/investmentcosts/>
- World Bank. (2009). *The Costs to Developing Countries of Adapting to Climate Change: New Methods and Estimates*.
- World Bank. (2017). *World Development Indicators*. Retrieved August 1, 2015, from

<http://data.worldbank.org/indicator>

World Bank, & United Nations. (2011). *Natural Hazards, UnNatural Disasters – The Economics of Effective Prevention*. Washington, D.C. Retrieved from https://www.gfdr.org/sites/gfdr/files/publication/NHUD-Report_Full.pdf

Yang, W., Fidrmuc, J., & Ghosh, S. (2012). *Macroeconomic effects of government spending shocks: New evidence using natural disaster relief in Korea* (CESifo Working Paper No. 3943). Munich, Germany.

Zaracostas, J. (2011). Famine and disease threaten millions in drought hit Horn of Africa. *British Medical Journal*, 343.

Zylberberg, Y. (2012). *Natural natural disasters and economic disruption*. Barcelona, Spain.

Annex I. Detailed description of the econometric-based macroeconomic forecast model

In recent years, the body of literature investigating the effects of climate variability and change on macroeconomic outputs has significantly increased. Statistical and econometric approaches have been developed in addition to Integrated Assessment Model (IAM) approaches. The following section reviews and analyses most recent methods. By analysing the core strengths and limitations of the methodologies, we developed and adapted a unified approach to detect and forecast nonlinear relations between climate variables and macroeconomic output. The last section details how we forecast climate change impacts on macroeconomic outputs for the next decades using climate model (GCMs) outputs.

Existing and peer-reviewed methodologies

Dell, Jones, & Olken (2013a) published a working paper (WP) at the National Bureau of Economic Research (NBER) which comprehensively reviews recent methodologies to estimate the effects of climate change on economic growth. In their online appendix, the authors inventory a number of important studies estimating the impacts of climate variables on aggregate and sectoral outputs using statistical or/and econometric approaches. Taking into account this diversity of studies as reviewed in the WP, we specifically investigate studies that apply different methodological approaches, including different time and space resolutions, and analysed economic outputs. The methodology of this paper is a unified approach stemming from the following three studies of varying methodologies:

- Dell, Jones, & Olken, 2012, for the level and growth effect of inter-annual climate variability,
- Brown, Meeks, Ghile, & Hunu, 2013, for the investigation of intra-annual variability on different economic sectors using a predefined precipitation index,
- Schlenker & Roberts, 2009, for the methodology detecting the nonlinear influence of climate variables on output.

Level effect and growth effect of weather shocks (Dell et al., 2012a)

Brief summary of the paper:

This paper thoroughly investigates the effects of climate variability, e.g., temperature and precipitation, on macroeconomic output, including GDP per capita, agricultural value added, industrial value added, and growth in investment. The study also assesses the lagged effects of climate variability for a period of 1 to 10 years. The authors only find a statistically significant decrease in GDP growth for an increase in temperature, and not for precipitation variability. For sub-Saharan Africa, they estimate that a 1°C increase in temperature leads to a decrease by 1.8 percentage points in GDP growth, with a high statistical significance.

Methodology applied (growth function and regression):

Authors use annual average precipitation and temperature at 0.5° by 0.5° horizontal resolution from 1950-2005 (corresponding to 56 by 56 km at the equator), taken from Terrestrial Air Temperature and Precipitation: 1900–2006 Gridded Monthly Time Series, Version 1.01 (Matsuura & Willmott, 2007)⁴⁵ as independent variables to run the regression. Different from the Brown et al. (2013) paper (see below), the study does not account for intra-annual climate variability, and only accounts for inter-annual variability, i.e. the year-to-year variation of climate variables. The growth function in the study is dynamic in the way that it distinguishes between short-term level effects on output β and the growth long-term effects γ and integrates the effects of last year's climate variability in the regression with βT_{it-1} .

- Dynamic growth function:

$$g_{it} = g_i + (\beta + \gamma)T_{it} - \beta T_{it-1}$$

Variables	Description
g_{it}	Growth rate of per capita output at time t in country i
β	“Level effects” of weather shocks
γ	“Growth effects” of weather shocks
T_{it}	Vector of annual average temperature and precipitation, at time t in country i
g_i	Change in labour productivity without weather changes, specific to country i

For the regression, authors used country θ_i and time θ_{rt} fixed effects. Time-variant fixed-effects are defined at the regional level, and account for specific regional conjectural effects that are not climate-related. Similarly, the country fixed-effect accounts for time-invariant variables specific to the country (such as topography, culture, etc.). The regression is run for panel data of 125 countries. They distinguish between rich and poor countries, with poor country being defined as having *below-median PPP-adjusted per capita GDP in the first year the country enters the dataset*. The term $\sum_{j=0}^L \rho_j T_{it-j}$ allows the calculation of lagged effects (L) of past climate variability on actual economic output.

- Fixed effect regression:

$$g_{it} = \theta_i + \theta_{rt} + \sum_{j=0}^L \rho_j T_{it-j} + \varepsilon_{it}$$

Variables	Description
θ_i	Country fixed effect
θ_{rt}	Time fixed effect, interacted separately with region dummies and a poor country dummy in the main specifications of the regression
ε_{it}	Standard error (clustered by country and region-year)
L	Time lags
ρ_j	Coefficient of lag effect of weather shocks for j number of years

Interests of the study and methodology:

⁴⁵ <http://climate.geog.udel.edu/~climate/>.

- The regression function allows for the integration of time-lagged effects of different duration. The function is particularly time-/lag-flexible;
- The growth function accounts for both level and growth effects of climate variables on economic outputs;
- The regression model can also be used to estimate effects of climate variability on different GDP components (in the study, agriculture, industry and investments). For investments, authors used gross fixed capital formation from the Penn World Table;
- The time-variant fixed effect is defined at the regional level.

Limitations for the study:

- The results of the study contradict the results of Brown et al. (2013): temperature variability has a very significant effect whereas precipitation plays a minor role. However, this limited effect can be explained by the absence of normalization of the precipitation data in a panel regression.
- The study only estimates the effects of inter-annual variability on economic output without looking at seasonality, which is likely to increase in a context of changing climate.
- The econometric model developed is linear and does not account for the consequences of extreme hot temperature periods, which could have stronger effects on macroeconomic outputs (see for example Felbermayr & Gröschl, 2013, for the effects of the most extreme disasters on GDP).

Intra-annual variability using a predefined index (Brown et al., 2013)

Brief summary of the paper:

The paper complements the Dell et al. (2012) study. In that study, authors find that precipitation variability, including drought and floods, has a lower effect on GDP growth than temperature variability. In addition, precipitation variability is not statically significant; the only statistically significant result for precipitation is a decrease of GDP by 0.08 percentage points in rich countries for an additional 100mm of precipitation. Brown et al. apply very similar growth and regression functions. However, in order to capture both spatial and temporal variability of precipitations, they apply a weighted anomaly standardized precipitation (WASP) index developed by Lyon & Barnston, (2005). When the index has a value superior to 1 and inferior to -1, it respectively reveals the occurrence of an anomalously wet event (potentially floods) and an anomalously dry event (potentially droughts) for a specific geographical location, determined as being a 0.5° grid cell. Using the WASP index, they find that an increase by 1 per cent of country area exposed to $WASP < -1$ is associated with a reduction in GDP per capita by 2.7 per cent and an increase by 1 per cent of country area exposed to $WASP > 1$ is associated with a reduction in GDP per capita by 1.8 per cent.

Methodology applied (growth function and regression):

Authors use a WASP index (see calculation below) as one of the independent variables in the study along with non-standardized precipitation and temperature variables.

- Weighted Anomaly Standardized Precipitation (WASP):

$$S_N = \sum_{i=1}^N \left(\frac{P_i - \bar{P}_i}{\sigma_i} \right) \frac{\bar{P}_i}{\bar{P}_A}$$

for N=12

Variables	Description
P_i	Observed precipitation for the i th month
$\bar{P}_i$	Long-term average for the i th month
σ_i	Standard deviation of monthly precipitation for the i th month
$\bar{P}_A$	Mean annual precipitation

country and time fixed effects in a linear model. Country α_i and time ϕ_t fixed effects are employed to remove time invariant country-specific effects and conjectural global effects (not regional, unlike the Dell et al. 2012 paper). Regression is run using panel data of 133 countries. Lagged values are also used as independent variables in order to estimate the effects of last year's climate variability on present year's GDP.

- Fixed effects regression:

Without lagged values $Y_{it} = \beta X_{it} + \alpha_i + \phi_t + \varepsilon_{it}$

With lagged values $Y_{it} = \beta X_{it-1} + \alpha_i + \phi_t + \varepsilon_{it-1}$

Variables	Description
Y_{it}	Livelihood measure, at time t in country i
α_i	Country fixed effect
ϕ_t	Year effect
ε_{it}	Standard error, time-variant factors
β	Effect of weather shocks on livelihood measure
X_{it}	Climate measures, at time t in country i

Interests of study and methodology:

- The WASP index takes intra-annual variability, and allows for a comparison of the current climate variability to a historical climate variability,
- The use of an index allows for a relative comparison between precipitation levels, while absolute precipitation levels as used in the Dell et al. (2012) method does not capture the effects of macroeconomic outputs in relative change in precipitation.
- The regression function allows for a consideration of the percentage of geographical area exposed to a specific range of the index,
- Regressions were run using precipitation and temperature as well as WASP index, for different time-lagged values. In total, authors used 9 different models specifications of independent variables (P; T; P,T; W+1; T, W+1; W-1; T, W-1; T, W-1, W+1; W-1, W+1) to test statistical relation between economic output and climate variables.

Limitations for the study:

- The WASP index and the regression were only employed for panel data of 133 countries. The same regression may not be usable at the individual level to find statistically significant parameters at the national level, due to the limited number of observations,

- When using observations for WASP<-1 and WASP>1, the number of observations decreases from 4,898 to 1,686. Applied to a smaller number of countries (65 countries, territories or unrecognized States in the case of Africa), the number of observations may also significantly decrease, limiting the statistical significance of the results – and even more at the national level,
- The effects of change in climate variability are linear,
- The time-variant fixed effect is defined at the global level.

Non-linear relationship between climate variables and output (Schlenker & Roberts, 2009)

Brief summary of the paper:

Schlenker & Roberts (2009) estimate the effects of temperature change on crop yields in the US. They find that the relationship between temperature variability and crop yields is nonlinear, with temperature reaching an optimal level and then any further increase in temperature leads to a steep decrease in crop yields. To project the future effects of climate change on crop yields, they estimate yields by using temperature intervals. To every temperature interval they associate a cumulative heat distribution function noted $\phi_{it}(h)$ for the specific interval for the county i and year t . More recently, Bezabih, Di Falco, & Mekonnen (2014) replicated this approach to estimate the effects of climate variability on crop production in Ethiopia. The main argument for using this method is the ability of the mode to detect nonlinear patterns and breakpoints in the effects of temperature on yield; similar methodology could be replicated for economic output.

Methodology applied (growth function and regression):

$$Y_{it} = \int_{\underline{h}}^{\bar{h}} g(h)\phi_{it}(h)dh + z_{it}\delta + c_i + \varepsilon_{it}$$

Whichwhich becomes:

$$Y_{it} = \sum_{j=0,3,6,9...}^{39} \gamma_j [\phi_{it}(h+3) - \phi_{it}(h)] + z_{it}\delta + c_i + \varepsilon_{it}$$

They analyse the effects of a three-degree interval (j) from -1°C to 39°C.

Variables	Description
$g(h)$	Plant growth depending nonlinearly on heat (h)
$\phi_{it}(h)$	Time distribution of heat over growing season in county i, year t
z_{it}	Other control variables, including quadratic in total precipitation, quadratic time trends by state
c_i	Time-invariant country fixed effect
ε_{it}	Error term

Interests:

- The econometric model can detect/project nonlinear patterns and breakpoints in the relationship between climate variability and crop yields, which is of significant interest for the research project,

- The regression method can project nonlinear patterns and breakpoints in the relationship between climate variability and crop yields, which is of significant interest for the research project.
- The choice of independent variables is to be tested, but it could be feasible to add temperature, precipitation in a standardized way or not (WASP or precipitation, temperature intervals).

Limitations of the study:

- The method has so far (and to the best of our knowledge) never been applied to economic output such as economic growth and sectoral outputs,
- The model only analyses the effects of a single independent variable i.e. temperature on yields, and only uses precipitations as a control variable,
- Key difference between crops and economic outputs is stationarity, the effects of X degree of temperature on a specific crop is constant over time – whereas societies can adapt to climate signals, limited recovery from an earlier event can have more severe consequences and overall economic structure can evolve. The stationarity or non-stationarity of the relation between the effect on economic output and a specific intensity of climate variable vectors could be tested by plotting on the x-axis the years when the events of intensity (*I*) occurred against the effects on GDP (y-axis).

Detecting climate-macroeconomics nonlinear patterns

Core elements of interest

The proposed approach to estimate the effects of climate variability on macroeconomic output and forecast the effects of future climate change capitalizes on the main strengths of the three existing methodologies reviewed above:

- The decomposition of countries' macroeconomic indicators by accounting for specific time-invariant country conditions that can influence economic output and GDP growth (Schlenker & Roberts, 2009), and by integrating regional and global economic shocks that may have had an effect on all countries' socioeconomic trends;
- The capacity to detect and project nonlinear patterns and breakpoints (Schlenker & Roberts, 2009) in the relationship between climate shocks and macroeconomic variables, as well as the steady-climate state level in which countries perform at their optimum (Burke et al., 2015);
- The integration of time-lagged effects as independent variables (Dell et al., 2012a) in order to account for long-term positive (growth rebound following a disaster or reconstruction) and negative consequences of climate-related disasters;
- The decomposition of overall economic output in sectoral economic output or components of GDP (Brown et al., 2013; Dell et al., 2012a), to integrate the influence of future structural economic changes (share of the respective sector in the total aggregate output) on the sensitivity of the economy to climate shocks;
- The estimation of the effect of independent variables using a predefined index that takes into account intra-annual climate variability (Brown et al., 2013) and percentage of exposed area, especially with respect to precipitation patterns, which show large variability across countries and regions in Africa and globally.

Normalizing precipitation and to a lesser extent temperature is a key condition for panel regression of countries' macroeconomic and climatological conditions.

Detailed description of variables, and data requirements

Specification of climate data

$X_{it,l}$ represents the percentage of area in a country (i) at a specific time period (t) that is exposed to the same range of intensity (l) of a derived climate index. The percentage of area exposed to (l) is defined as the percentage grid points having an index value within a specified range (l) to the total number of grid points within a country.⁴⁶ Each grid point is also weighted according to the country population. For example, a grid box with a weight of 0.1 implies that 10 per cent of the country's population resides within that specific grid box. Depending on the datasets used, the spatial resolution of the grid points could either be 200km or 50km. The applied climate variability index is the Standardized Precipitation Index (SPI). The intervals l of the SPI are defined using a 0.5 index point increment, forming a total of 10 segments from below -2 to above +2. [As an example, Schlenker & Roberts (2009) had clustered temperature in three-degree temperature intervals ranging from -1°C to 39°C.]

The main requirement for the data used for climate variability is that the same or similar spatial and temporal resolution can be found in the data coming from the General Circulation Model (GCM) or Regional Climate Model (RCM) used for the forecast.

Standardized Precipitation Index (SPI)

The SPI is a powerful, yet flexible index for monitoring both dry and wet conditions at multiple time scales (McKee et al., 1993). The SPI is based on the probability of precipitation being higher or lower than the median precipitation. Negative SPI values thereby indicate dry conditions while positive SPI values indicate wet conditions (see table below). The SPI can be computed at different time scales, e.g. 1 month, 6 months, or 12 months. At shorter time scales, the SPI is highly sensitive to monthly precipitation changes and thus captures short-term extreme events (e.g. flash floods, dry spells, affecting water resources like surface waters, river flow and runoff). If computed at longer time scales, it also includes changes during previous time steps (e.g. months), making it an appropriate index for longer-lasting extreme conditions (e.g. persistent droughts, affecting slower-response resources such as soil and groundwater). A major advantage of the SPI is its spatial comparability across different climate zones, making it particularly interesting for climatically heterogeneous regions like Africa.

Table 7 SPI values and their climatological implication. The SPI is standardized in the sense that probabilities (share of cases) follow standard-deviation distances or follow a normal distribution.

SPI value	Category	Probability (share of cases) (%)
2.00 or more	Extremely wet	2.3
1.50 to 1.99	Severely wet	4.4
1.00 to 1.49	Moderately wet	9.2

⁴⁶ Country borders are provided by *Natural Earth* (<http://www.naturalearthdata.com>).

0.00 to 0.99	Mildly wet	34.1
-0.99 to 0.00	Mild drought	34.1
-1.49 to -1.00	Moderate drought	9.2
-1.99 to -1.50	Severe drought	4.4
-2.00 or less	Extreme drought	2.3

Annual-mean temperature time series

In addition to the SPI, which accounts for the precipitation variability, annual mean temperature accounts for the overall warming of each African country. As for the SPI exposure, the time series of annual-mean temperature for each country are area-weighted according to the country population.

Climate data sources

Historical SPI data are derived from the observational precipitation data provided by the *Global Precipitation Climatology Centre* (GPCC) (Schneider et al., 2011). The GPCC precipitation is based on precipitation station data. The data set used in this report⁴⁷ has a horizontal resolution of 1° by 1° and a temporal resolution of one month.

Historical temperature data are derived from the global gridded temperature data set provided by Berkeley Earth Temperature (Rohde et al., 2013). The temperature data is based on observational temperature records, which have been homogenized and corrected for consistency. The data set used in this report⁴⁸ has a horizontal resolution of 1° by 1° and a temporal resolution of one month.

Data for the two future projections based on the RCP2.6 and RCP8.5 scenarios was taken from the ISI-MIP global climate database (Hempel et al., 2013), which consists of five bias-corrected CMIP5 models (gfdl-esm2m, hadgem2-es, ipsl-cm5a-lr, miroc-esm-chem, noresm1-m). More precisely, temperature and precipitation data were bias-corrected based on a comparison of model outputs with observational WATCH forcing data over a 40-year record. The correction factors deriving from a regression were then applied to the model output (Hempel et al., 2013). The model data has a horizontal resolution of 0.5° by 0.5° and temporal resolution of one month.

Socioeconomic data sources

Historical GDP data used for this assessment were: World Bank, (2015) for Southern and Northern Africa, and Penn World Table for the other African regions for the period 1980 to 2014. Agricultural, industry and services value added data were sourced from the World Bank (2015). Conflicts data are used as dummy variable in the model, dataset was sourced from Pettersson & Wallenstein (2015).

The following variables are used as control variables: annual international oil price (source: International Energy Agency), government final consumption expenditures (source: World Bank, 2015), remittances (source: World Bank, 2015), total external debt stock (source: World Bank, 2015), trade openness (calculated using import and

⁴⁷ Data are obtained from

<ftp://ftp.cdc.noaa.gov/Datasets/gpcc/combined/precip.mon.combined.total.v6.nc>.

⁴⁸ Data are obtained from <http://berkeleyearth.org/data>.

export data from: World Bank, 2015), governance (Polity2) and total public assistance (source: World Bank, 2015) and ODA (source: World Bank, 2015). To avoid risk of endogeneity between the control variables and the dependant variables, we use 1-year lagged control variables similarly to Felbermayr & Gröschl (2013).

Potential limitations of the approach

Several limitations may affect upwards or downwards the overall reliability of the results of the economic model:

- The approach relies on the principle of climate analogues, therefore only already experienced climate-related events can be modelled. Events unprecedented in their intensity could not be modelled.
- The use of control variables limits the degrees of freedom of the econometric analysis.
- The process of model calibration provides more accurate sensitivity coefficients at the country-level but could also force the model into the selection of coefficients.

Annex 1. Specifications and description of the AD-AFRICA model

This annex provides a short description of the AD-AFRICA model and its calibration. AD-AFRICA is a Ramsey-type growth model with explicit representation of adaptation to climate change, where the adaptation and damage module are based on the AD-RICE model (K. de Bruin et al., 2009; K. C. de Bruin et al., 2009). The model comprises five regions, which together represent Africa. The regions included in the model are as follows: North, South, East, West and Middle. Climate change impacts are modelled for seven sectors: Coast, Health, Tourism, Fisheries, Agriculture, Roads and Water.

The AD-AFRICA model is an Integrated Assessment Model (IAM) for Africa, where economic production leads to GHG emissions. In this model, industrial CO₂ is the only endogenous GHG. In the context in which the model is used here, however, temperature and sea-level rise paths are given exogenously. Though climate change includes a multitude of phenomena (such as changes in precipitation, changes in weather variability, increased extreme weather), it is represented by changes in atmospheric temperature, regional temperature and sea-level rise in this model. Overall, climate change negatively affects society and the economy through various different impacts. GDP impacts due to climate change are modelled as a percentage decrease in production as a function of mean global and regional atmospheric temperature change as compared to 1900 and sea-level rise as compared to 1900.

AD-AFRICA is a forward-looking Ramsey growth model, where utility is maximized over the model horizon. The model has time periods of five years and has a time horizon of 200 years. Utility is a function of consumption per capita discounted over time and over income per capita (richer generation's consumption creates less utility than poorer generation). The model finds the optimal balance of capital investments, mitigation investments, adaptation investments, adaptation costs and consumption to maximize utility.

The climate change damage estimates in the AD-AFRICA model are estimated based on seven impact sectors. We have chosen these sectors based on the extent of their overall impact and the availability of data. Given the obvious data restrictions, this list is not comprehensive and many impacts of climate change remain unquantified. The AD-AFRICA model uses a stylized damage function where temperature increases lead to direct decreases in production. A more detailed description of damages would include a production function approach, which includes the effects on production inputs and direct utility effects. There remains a large degree of uncertainty regarding the damages associated with climate change, where particularly many impacts have not yet been identified or quantified. The quantified damages in this model could be seen as a lower bound to expected climate change damages, but damages could be significantly higher than projected.

The AD-AFRICA model includes two forms of adaptation, namely, proactive adaptation and reactive adaptation. This distinction has been made to enable a more accurate description of the costs and benefits of different forms of adaptation and hence the total adaptation costs. Reactive adaptation describes adaptation measures that can be taken in reaction to climate change or climate change stimuli. This form of adaptation comes at a relatively low cost and is generally undertaken by individuals.

Examples of this form of adaptation are the use of air-conditioning or the changing of crop planting times. Proactive adaptation on the other hand refers to adaptation measures that require investments long before the effects of climate change are felt. This form of adaptation usually requires large-scale investments made by Governments. Examples of this form of adaptation are research and development into new crop types or the construction of a dam for irrigation purposes.

Damages are estimated in each of the following impact sectors; Agriculture, Health, Fisheries, Energy, Water, Coastal, Roads and Tourism, denoted by i . Gross damages (damages before adaptation) in each impact sector are a function of global atmospheric temperature change ($TATM_t$), regional atmospheric temperature change ($RATM_{j,t}$) or sea-level rise ($SLR_{TOT,t}$). Gross damages are generally defined as follows; some sectors include a more complex description and are discussed in de Bruin and Said (forthcoming):

$$(8a) GD_{j,t,i} = \alpha_{1,j,i} \cdot TATM_t + \alpha_{2,j,i} \cdot TATM_t^{\alpha_{3,j,i}}$$

$$(8b) GD_{j,t,i} = \alpha_{1,j,i} \cdot RATM_{j,t} + \alpha_{2,j,i} \cdot RATM_{j,t}^{\alpha_{3,j,i}}$$

$$(8c) GD_{j,t,i} = \alpha_{1,j,i} \cdot SLR_{TOT,t} + \alpha_{2,j,i} \cdot SLR_{TOT,t}^{\alpha_{3,j,i}}$$

These are the damages that occur if no adaptation takes place and are thus higher than the net damages. These damages can be reduced through the use of adaptation. We assume the following relationship:

$$(9) RD_{j,t,i} = \frac{GD_{j,t,i}}{1 + P_{j,t,i}}$$

where $P_{j,t,i}$ is the total level of protection (stock and flow) $RD_{j,t,i}$ and are the residual damages. This functional form is chosen because it limits the fraction by which the gross damages can be reduced to the interval of 0 to 1. When total protection reaches infinity, all gross damages are reduced (the residual damages are zero) and when no protection is undertaken no gross damages are reduced (residual damages equal gross damages). This functional form also ensures decreasing marginal damage reduction of protection, that is the more protection is used the less effective additional protection will be. It is thus assumed that more effective and efficient measures of adaptation will first be applied, followed by less effective measures.

We now define how our two forms of adaptation (stock and flow) together create total adaptation. The two forms of adaptation are aggregated together using a Constant Elasticity of Substitution (CES) function. Here the elasticity of substitution can be calibrated to reflect the observed relationship between the two forms. This function is given as follows:

$$(10) P_{j,t,i} = \gamma_{1,j,i} \cdot (\nu_{1,j,i} SAD_{j,t,i}^{\rho_A} + \nu_{2,j,i} FAD_{j,t,i}^{\rho_A})^{v_{1,j,i}/\rho_A}$$

where $SAD_{j,t,i}$ is the total amount of adaptation capital stock and $FAD_{j,t,i}$ is the amount spent on reactive adaptation in that period. Furthermore, $\rho_A = \frac{\sigma-1}{\sigma}$, where σ is the elasticity of substitution.

Adaptation capital stock is built up as follows:

$$(11) SAD_{j,t+1,i} = (1 - \delta_k)SAD_{j,t,i} + IAD_{j,t,i}$$

where δ_k is the depreciation rate and $IAD_{j,t,i}$ are the investments in stock adaptation (SAD_t).

The total adaptation costs in each period are thus;

$$(12) PC_{j,t,i} = FAD_{j,t,i} + IAD_{j,t,i}$$

The net damages are the sum of residual damages and adaptation costs. Therefore, combining the previous equations we have:

$$(13) D_{j,t,i} = RD_{j,t,i} + PC_{j,t,i} = \frac{GD_{j,t,i}}{1+P_{j,t,i}} + FAD_{j,t,i} + IAD_{j,t,i}$$

The adaptation module of AD-AFRICA is calibrated on the basis of estimates of adaptation costs and benefits from the impact literature. More precisely, for each climate impact sector the adaptation costs and benefits for each region were estimated based on available impact studies and expert judgment. For a full description of this process, please refer to de Bruin and Said (forthcoming).

Climate change is global environmental problem, affecting all regions of the world both now and in centuries to come. Both the causes of climate change (different sources of GHG emissions) and the effects of climate change are innumerable, diverse, and vary in scope and scale. Attempting to include all causes and effects of climate change in a single model is a difficult task. In particular, estimating the effects of climate change in the long run is a complex process, which involves many uncertainties. IAMs are tools created to assess the effects of the economy on climate change and vice versa in the long run. Due to the many mechanisms involved and the long time frame, these models need to make (simplifying) assumptions. IAMs are hence highly aggregated top-down models, which do not include all sectoral and regional impacts in detail. Though these assumptions and simplifications are necessary due to both lack of data (it is hard to predict future effects) and computational limitations, they do form a significant drawback of IAMs. Notwithstanding these drawbacks, applying a model such as AD-AFRICA can still give important insights into the magnitude and development of both the economy and the climate. Given that climate change is both a global problem and will have the greatest effects in the long term, an analysis of climate change is incomplete without a global long-term perspective. The strength of IAMs such as AD-AFRICA is that they can shed some light on the long-term climate consequences of our actions now.

Annex 3. Comparison with earlier AD-RICE model

In Schaeffer et al. (2013, 2014), the AD-RICE model was applied to estimate future adaptation and damage impacts in Africa. Here we compare the results of the two models and examine the underlying reasons for different results.

Figure 8.1 shows the total net damages for Africa as a whole for the AD-RICE and AD-AFRICA models in 2050. In 2050 the residual damages are higher in AD-AFRICA, but the adaptation costs are lower. As the coastal sector plays an important role in total damages in the AD-RICE model, we also present the net damage components in AD-RICE without the coastal sector. Without the coastal sector adaptation investments are half and of a similar magnitude to AD-AFRICA.

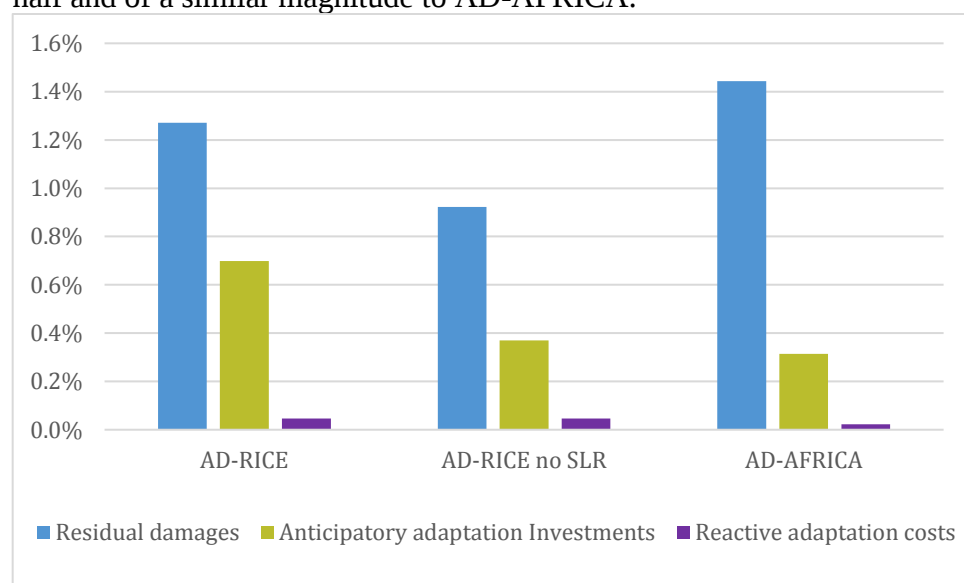


Figure 1 Total net damages: residual damages, anticipatory investments and reactive adaptation costs in 2100 for Africa as a whole for the above 4°C world as a percentage of GDP

In 2100, the differences in results between the two models is larger, where the AD-RICE damages are much higher. To understand why this is the case, we examine the impacts in different sectors in both models. Figure 8.2 presents the net damages in different sectors for each model. Health impacts are much larger in the AD-RICE model in 2100; this is because AD-RICE does not consider the impacts of socioeconomic development on health impacts, reducing these impacts irrespective of adaptation efforts. Coastal damages are also larger in AD-RICE, as explained earlier, where impacts are estimated based on willingness to pay in the United States, which is extrapolated to Africa. Agricultural impacts are much larger in AD-AFRICA, which can be explained by the literature evidence base of AD-AFRICA, which draws exclusively from recent studies on the agricultural sector for Africa, while AD-RICE draws from older, highly aggregated studies (Darwin, 1995). Besides these three sectors, each model includes different additional sectors, labelled other sectors in the graph. Impacts in other sectors are slightly larger in AD-RICE, which includes catastrophic events, energy and water markets, ecosystems and settlements and non-

market time use. This shows the importance of including all impact sectors within a single model.

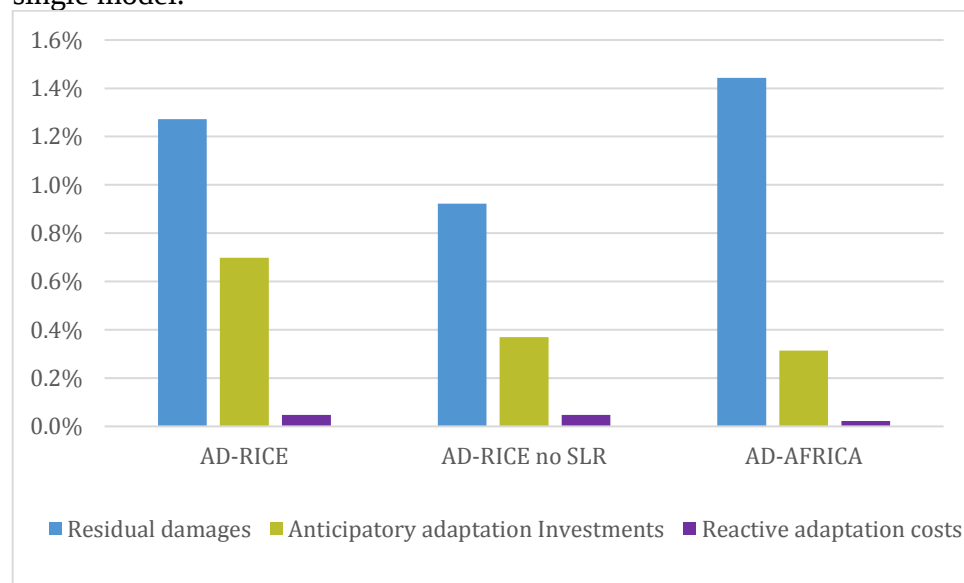


Figure 2 Net damages in 2100 for Africa as a whole for various sectors for the above 4°C world as a percentage of GDP

Annex 4. Details on methodology used in chapter 6: Opportunities

Scope and data sources

In this section we will quantify three co-benefits of climate mitigation policies in Africa: job creation in the renewable sector, improved energy security and reduced premature mortality induced by fine dust. These are chosen because they are crucial hurdles to Africa's further development. We quantify co-benefits originating from policies such as promotion of renewable energy.

Table 3 Overview of quantified mitigation co-benefits

Co-benefits	Sector	Proxy	Examples for policy types
Improved energy security	Energy	Energy self-sufficiency, energy self-sufficiency net of exports, import dependency, energy intensity	Active promotion of renewable energy through tax and investment incentives (financial and administrative in nature); inclusion of negative externalities of use of fossil fuels in its cost through taxation or elimination of subsidies (if applicable)
Employment creation	Labour market	Net annual potential employment in manufacturing, construction and installation (MCI), and operation and maintenance (OM) of energy sources for electricity	Active promotion of renewable energy to users by increasing awareness on the benefits in terms of sustainability and access, especially for rural areas, and health benefits of avoiding use of fossil sources; early preparation of labour force for renewable sector-specific skills through capacity-building and knowledge transfers
Less air pollution and improved health	Health	PM _{2.5} distribution data	Standards and norms on (improved) filtering systems

For these quantifications, most of the data were derived from the LIMITS database (Low climate IMPact scenarios and the Implications of required Tight emission control Strategies).⁴⁹ The LIMITS project's main objective is to provide an assessment of emissions reduction strategies and their implementation on a worldwide scale (Kriegler et al., 2014a). Overall, the LIMITS database compares seven integrated assessment models of climate change (IAMs). Because of model specifications, we provide co-benefit calculations based on the models REMIND (Regionalized Model of

⁴⁹ The data base can be freely accessed via this link: <https://tntcat.iiasa.ac.at/LIMITSPUBLICDB/dsd?Action=htmlpage&page=welcome>. For more information, see <http://www.feem-project.net/limits/index.html>.

Investments and Development)⁵⁰ and MESSAGE (Model for Energy Supply Systems And their General Environmental Impact).⁵¹ REMIND is used for quantifying job creation in the renewable sector and energy security. This model limits the African region to sub-Saharan Africa (excluding South Africa). Because data are only available for the overall region, we quantify these co-benefits on a continental scale for sub-Saharan Africa. Note that this model was not originally designed to analyse the labour market. In order to do so, we employed some additional exogenous assumptions to the initial REMIND model output. Due to the uncertainties in our assumptions, the results presented in section 6.2.2 can only provide a first-order approximation of the amount of jobs created by the renewable industry.

The health benefits of reduced fine dust from burning fossil fuels are derived on the basis of the MESSAGE model.⁵² Health benefits are analysed on a national basis as we have data for all African countries or regions except for Western Sahara, South Sudan and the Sudan.

To analyse the co-benefits of climate mitigation and adaptation in comparison to non-action we choose two LIMITS scenarios. The baseline scenario is Reference (Reference Policy scenario, also called business-as-usual scenario) and the more ambitious scenario is 2°C (Reference Policy limiting greenhouse gas concentrations to about 450 parts per million (ppm)). The Reference scenario assumes weak and fragmented policy action without a specific temperature limit or concentration target. Pre-2020 climate policy is assumed to follow the Copenhagen pledges. Post-2020 climate policy is based on a continuation of these pledges. In the 2°C scenario such fragmented action is only pursued until 2020. After that year cooperative action is taken to limit greenhouse gas concentrations to 450–480 ppm CO₂ equivalents (Kriegler et al., 2014b). This implies a target level of 2.8 W/m² of radiative forcing in the year 2100. At this level, the chances of exceeding the 2°C limit in 2100 are 20–41 per cent (Kriegler et al., 2014b). For non-LIMITS data we use comparable scenarios.

Further data sources are used. The technology specific load factors are from the World Energy Investment Outlook (WEIO) published by the International Energy Agency (WEIO, 2014). We assume that the LIMITS scenarios Reference and 2°C are comparable with the New Policy Scenario and 450 Scenario respectively.⁵³ Additionally these load factors are assumed to be constant after 2035. Other data sources will be indicated in the following methodology section.

The co-benefits are analysed for the period from 2020 to 2050. We selected this starting year as policies are assumed to be fixed up to 2020 in both scenarios.

⁵⁰ A description of this general equilibrium model is provided here: <https://www.pik-potsdam.de/research/sustainable-solutions/models/remind/description-of-remind-v1.5>.

⁵¹ For more information, see:

<http://www.iiasa.ac.at/web/home/research/researchPrograms/Energy/MESSAGE.en.html>.

⁵² We would like to thank Rita Van Dingenen (Scientific Officer at the Air & Climate Unit, Institute for Environment and Sustainability, Joint Research Centre, European Commission for providing us with this data.

⁵³ For further information on these scenarios, see:

<http://www.iea.org/publications/scenariosandprojections/>.

As pointed out by other studies (e.g. (IRENA, 2012b)), projections for the time scale up to 2050 are uncertain, as Africa is a rapidly changing and growing market, but this analysis provides indications for the differences between both scenarios (Reference and 2°C).

Table 4 Scenario design and naming convention of the LIMITS WP1 study (source: <https://tntcat.iiasa.ac.at/LIMITSDB/dsd?Action=htmlpage&page=about>)

Scenario Name	Scenario Type	Near-term Target / Fragmented Action	Fragmented Action until	Long-term Target, in 2100	Burden-sharing
Base	Baseline	None	N/A	None	None
RefPol	Reference	Weak	2100	None	None
StrPol	Reference	Stringent	2100	None	None
450	Benchmark	None	N/A	450 ppm CO ₂ e (2.8 W/m ²)	None
500	Benchmark	None	N/A	500 ppm CO ₂ e (3.2 W/m ²)	None
RefPol-450	Climate Policy	Weak	2020	450 ppm CO ₂ e (2.8 W/m ²)	None
StrPol-450	Climate Policy	Stringent	2020	450 ppm CO ₂ e (2.8 W/m ²)	None
RefPol-500	Climate Policy	Weak	2020	500 ppm CO ₂ e (3.2 W/m ²)	None
StrPol-500	Climate Policy	Stringent	2020	500 ppm CO ₂ e (3.2 W/m ²)	None
RefPol-2030-500	Climate Policy	Weak	2030	500 ppm CO ₂ e (3.2 W/m ²)	None
RefPol-450-PC	Climate Policy	Weak	2020	450 ppm CO ₂ e (2.8 W/m ²)	Per-capita Convergence
RefPol-450-EE	Climate Policy	Weak	2020	450 ppm CO ₂ e (2.8 W/m ²)	Equal Mitigation Effort

Health benefits of reduced air pollution

As stated in the section, air pollution can be measured by air's content of fine particulate matter (PM_{2.5}). For our calculations, we assume that all components of PM_{2.5} (e.g. ammonium sulphate and nitrate) are equally toxic (Lim et al., 2012b).

Table 5 Difference in yearly premature deaths due to air pollution as a co-benefit from mitigation, comparing a scenario without mitigation and a scenario in line with 2°C warming limit; absolute values refer to avoided deaths per country, relative values show avoided deaths per 100,000 inhabitants, based on population projections of the SSP2 (O'Neill et al., 2015)

Country	No. of deaths avoided (2010)	Per 100,000 (2010)	No. of deaths avoided (2030)	Per 100,000 (in 2030)	No. of deaths avoided in 2050	Per 100,000 (in 2050)
AGO	39.00	0.20	650.00	2.04	1222.00	2.78
BDI	-1.00	-0.01	110.00	0.84	319.00	1.90
BEN	-7.00	-0.08	77.00	0.54	249.00	1.30
BFA	-8.00	-0.05	40.00	0.15	200.00	0.52
BWA	4.40	0.22	187.47	7.72	211.00	7.71

CAF	0.00	0.00	52.00	0.85	176.00	2.37
CIV	-24.00	-0.12	262.00	1.00	744.00	2.43
CMR	-7.00	-0.04	449.00	1.64	1200.00	3.62
COD	100.00	0.15	2100.00	1.96	5100.00	3.50
COG	12.10	0.30	230.30	3.79	472.70	6.04
COM	0.04	0.01	1.86	0.18	3.61	0.28
CPV	0.00	0.00	0.50	0.09	1.30	0.23
DJI	0.30	0.03	12.90	1.09	39.70	2.88
DZA	0.00	0.00	300.00	0.67	1100.00	2.22
EGY	-100.00	-0.12	1100.00	1.03	3800.00	3.04
ERI	4.00	0.08	67.00	0.78	264.00	2.27
ETH	0.00	0.00	1300.00	1.05	4800.00	3.02
GAB	1.00	0.07	39.90	2.01	82.90	3.62
GHA	-27.00	-0.11	298.00	0.83	900.00	1.94
GIN	-8.00	-0.08	113.00	0.85	333.00	2.15
GMB	0.10	0.01	21.00	0.81	50.00	1.53
GNB	-0.20	-0.01	26.20	1.26	66.00	2.65
GNQ	0.29	0.04	18.90	1.72	46.30	3.21
KEN	5.00	0.01	493.00	0.81	1735.00	2.22
LBR	-5.00	-0.13	13.00	0.17	55.00	0.50
LBY	3.00	0.05	31.00	0.37	89.00	0.92
LSO	3.20	0.15	250.30	9.93	212.40	7.97
MAR	100.00	0.31	400.00	1.10	1300.00	3.51
MDG	1.40	0.01	116.70	0.35	230.00	0.51
MLI	-3.00	-0.02	27.00	0.10	100.00	0.28
MOZ	6.40	0.03	311.41	0.92	465.56	1.10
MRT	0.00	0.00	4.00	0.08	9.00	0.14
MUS	0.00	0.00	1.60	0.11	1.80	0.12
MWI	13.40	0.09	231.90	0.88	483.10	1.19
NAM	3.40	0.15	87.98	2.99	129.10	3.86
NER	-1.00	-0.01	0.00	0.00	300.00	0.59
NGA	-200.00	-0.13	1000.00	0.40	3300.00	0.89
RWA	-2.00	-0.02	137.00	0.81	451.00	1.96
SDN	0.00	0.00	400.00	0.60	1100.00	1.21
SEN	1.00	0.01	124.00	0.66	300.00	1.24
SLE	-4.00	-0.07	60.00	0.69	164.00	1.45
SOM	5.20	0.06	152.60	1.16	647.00	4.00
STP	0.12	0.07	1.95	0.98	2.65	1.26
SWZ	1.30	0.11	114.56	8.03	108.23	7.00
TCD	1.00	0.01	47.00	0.26	200.00	0.79
TGO	-6.00	-0.10	56.00	0.66	167.00	1.61
TUN	8.00	0.08	73.00	0.60	251.00	1.97
TZA	5.00	0.01	394.00	0.54	1219.00	1.19
UGA	-2.00	-0.01	530.00	0.88	2000.00	2.14
ZAF	100.00	0.20	5499.00	9.39	4774.00	7.57
ZMB	25.10	0.19	432.20	2.02	833.70	2.77

We use national data for deriving PM2.5 induced premature deaths in 2010, 2030 and 2050 for African countries. These data are derived with the energy supply model MESSAGE (called Model for Energy Supply Systems and their General Environmental Impact (MESSAGE)). It is a dynamic linear programming model, which minimizes the total costs of energy supply. We choose MESSAGE because it has a long history of pollution modelling and is part of the LIMITS project.

In this report, we consider two opposite climate mitigation scenarios: LIMITS1 and LIMITS6. The first assumes a world without climate mitigation, whereas the latter considers a 2°C mitigation scenario. Furthermore, we can choose from different air quality scenarios. We assume that the air quality legislation effective in 2010 prevails up to 2050. That is why we choose the air quality scenario CLE1 representing current (2010) legislation.

The absolute number of premature deaths is highest in the most populated countries (e.g. Nigeria, Egypt and Ethiopia). To display this risk in a comparable manner, we calculate the difference in premature deaths per 100,000 inhabitants between the LIMITS1 and LIMITS6 scenario:

$$Diff_{i,t} = PD_{LIMITS1,i,t} - PD_{LIMITS6,i,t}$$

with

$Diff_{PD,i,t}$ -Difference in scenarios' number of premature deaths per 100,000 inhabitants for country i at year t

$PD_{LIMITS1,i,t}$ -Premature deaths per 100,000 inhabitants under the scenario LIMITS1 for country i at year t

$PD_{LIMITS6,i,t}$ - Premature deaths per 100,000 inhabitants under the scenario LIMITS6 for country i at year t

We show this difference for all African countries for which we have data. The population data needed to calculate the number of premature deaths per 100,000 inhabitants uses projections from the SSP2 database (O'Neill et al., 2015).

Job creation in the renewables sector

For this report, we analyse the net employment creation potential in the energy sector in Africa based on derived installed capacity from electricity generation. We limit our calculations only to direct job creation, which is the employment directly induced by manufacturing, construction and installation (MCI), and operation and maintenance (OM) using employment factors found in Rutovitz & Harris (2012). Indirect and induced job creation for example in gastronomy and retail is very likely, but these second order effects are not covered in this report because they would need more detailed sectoral connectivity, such as those found in input-output models.⁵⁴

⁵⁴ For more information on intermediate job creation, see Ferroukhi et al. (2015). Rutovitz & Harris (2012) cite more references supporting evidence that the inclusion of indirect jobs increases numbers by 50-100 per cent, while direct and indirect induced jobs increase numbers by 100-350 per cent.

Our calculations are based on several assumptions. First, we assume that labour can move freely from one sector to another. This means that no education costs are considered.

Regarding technological change, the REMIND model uses an international learning curve implying that the technological standard is globally homogenous.

Moreover, our calculations assume that, production technique improvements reduce the needed employment per unit of electrical capacity over time, in line with the WEIO's assumption. And finally, we do not include jobs generated from decommissioning the use of a technology.

To calculate job creation for each technology y at time t we use the two selected scenarios (Reference and 2°C) from the REMIND model (LIMITS, 2013).

As a first step we calculate two capacities: newly installed capacities $AC_{y,t,s}$ for MCI and installed (operational) capacity $IC_{y,t,s}$ using secondary energy data on electricity generation from the LIMITS database. OM induced employment estimates make use of the total annual stock of installed capacity, while MCI estimates are based on the annual average change in installed capacities $AC_{y,t,s}$, representing the flow of investment in expanding capacities, net of depreciation. Because data projections in the REMIND model are in intervals of 10 years, we divide the difference in installed capacity by 10, to approximate a linear annual change in capacity.

$$AC_{y,t,s} = IC_{y,t+1,s} - IC_{y,t,s}$$

Total annual installed capacity is computed by taking the secondary energy $SE_{y,t,s}$ and dividing it by the technology-specific load factor $LF_{y,t,s}$:

$$IC_{y,t,s} = \frac{SE_{t,s}}{LF_{t,s}}$$

with

$IC_{y,t,s}$ – Installed capacity at time t for technology y given scenario s
 $SE_{y,t,s}$ – Secondary energy at time t for technology y given scenario s
 $LF_{y,t,s}$ – Load factor at time t for technology y given scenario s

The further calculation steps of MCI and OM job creation are similar but based on these two different flow ($AC_{y,t,s}$) and stock ($IC_{y,t,s}$) capacity types.

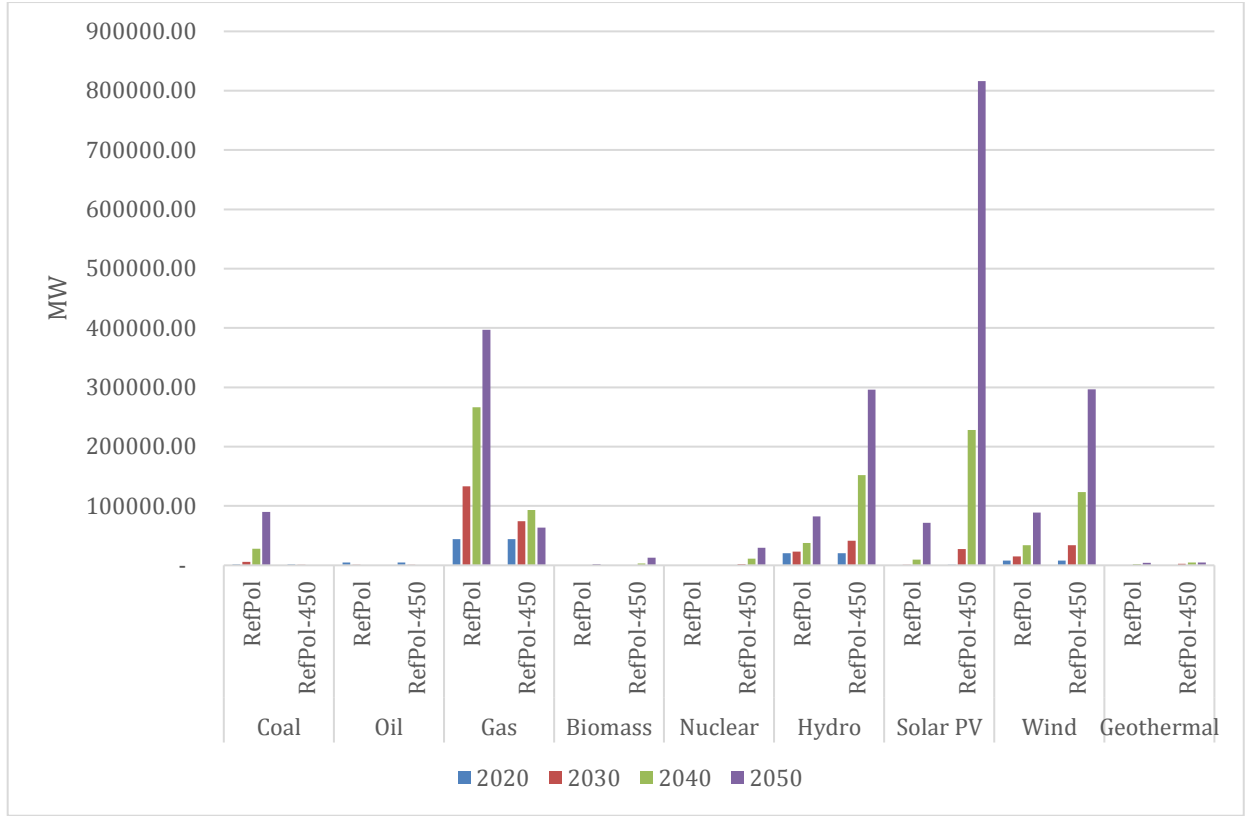


Figure 3 Total installed capacity [MW] by technology in sub-Saharan Africa

The induced employment from MCI activities ($MCI_{y,t,s}$) is computed by multiplying the annual average change in installed capacity by the adjusted employment factor for MCI ($AEF_{y,t}^{mci}$), where $EF_{y,t}^{mci}$ is the employment factor for OECD countries, and $R_{y,t}$ is the regional multiplier that adjusts the employment factor to fit Africa:

$$AEF_{y,t}^{mci} = EF_{y,t}^{mci} * R_{y,t}$$

$$MCI_{y,t,s} = AC_{y,t,s} * AEF_{y,t}^{mci}, \text{ if } AC_{y,t,s} > 0$$

The induced employment for OM activities ($OM_{y,t,s}$) is, on the other hand, computed by multiplying the total installed capacity by the adjusted employment factor for OM ($AEF_{y,t}^{om}$), where $D_{y,t}$ is the technology decline factor and z is the number of years after the last estimated factor as specified by Rutovitz & Harris (2012):

$$AEF_{y,t}^{om} = EF_{y,t}^{om} * R_{y,t} * (1 - D_{y,t})^z$$

$$OM_{y,t,s} = IC_{y,t,s} * AEF_{y,t}^{om}$$

	Construction times	MCI EF (job years/MW)	Regional Multiplier (2015)	Regional Multiplier (2020)	Regional Multiplier (2035)
Coal	5	11.9	1	1	1
Gas, oil, and diesel	2	1.5	4.3	4.2	4.6
Nuclear	10	16.0	1	1	1
Biomass	2	4.3	4.3	4.2	4.6
Hydro	2	11.3	1	1	1
Wind	2	15.0	4.3	4.2	4.6
PV	1	38.3	4.3	4.2	4.6
Geothermal	2	6.4	4.3	4.2	4.6

Figure 4: Multipliers for the computation of the adjusted employment factor for MCI-related activities

Source: Rutovitz and Harris (2012)

	OM EF (jobs/MW)	Regional Multiplier (2015)	Regional Multiplier (2020)	Regional Multiplier (2035)	Employment factor decline rate (2015- 2020)	Employment factor decline rate (2020- 2030)
Coal	0.3	1	1	1	0.3	0.5
Gas, oil, and diesel	0.05	4.3	4.2	4.6	0.3	0.6
Nuclear	0.66	1	1	1	0	0
Biomass	3.1	4.3	4.2	4.6	1.1	0.7
Hydro	0.4	1	1	1	-0.6	-0.9
Wind	0.4	4.3	4.2	4.6	5	2.35
PV	0.4	4.3	4.2	4.6	6.4	4.9
Geothermal	0.7	4.3	4.2	4.6	5.4	7.3

Figure 5: Multipliers for the computation of the adjusted employment factor for OM-related activities

Source: Rutovitz and Harris (2012)

Energy security

Meeting the growing energy demand is one of Africa's biggest challenges (Foster & Briceño-Garmendia, 2009). Currently about 60 per cent of people living in sub-Saharan Africa have no reliable access to clean and affordable energy sources, especially electricity (AfDB, 2014).

Many indicators exist for energy security. This section focuses on energy self-sufficiency and import dependence of Africa on external energy sources.

For this purpose, we calculated energy self-sufficiency ($ESS_{t,s}$) as proxy for energy security. It provides a percentage of domestic energy production over primary energy consumption:

$$ESS_{t,s} = \frac{P_{dom,t,s}}{C_{dom,t,s}} * 100$$

with

$ESS_{t,s}$: Energy self-sufficiency at time t for scenario s

$P_{dom,t,s}$: Domestic energy production at time t for scenario s

$C_{dom,t,s}$: Primary domestic energy consumption at time t for scenario s

Consequently, this ratio displays what percentage of domestic energy consumption is theoretically covered by domestic production. If $ESS_{t,s}$ is below 100 per cent, not all domestic consumption can be covered by domestic production. This means that the

region is not considered as energy self-sufficient as energy sources have to be imported. If $ESS_{t,s}$ is equal or above 100 per cent the region is defined as energy-self-sufficient, as all demand can be met by the domestic supply. Note that this indicator represents a *theoretical* level of energy security. For a more realistic scenario, we also calculated ESS less exports to account for continued attractiveness of the global market, as exports can take place even without reaching 100 per cent self-sufficiency. That is, exports are also determined by relative foreign and domestic energy prices, and do not only happen when an excess in supply is produced, relative to domestic demand.

$$ESSX_{t,s} = \frac{P_{dom,t,s} - X_{t,s}}{C_{dom,t,s}} * 100$$

with

$ESSX_{t,s}$: Energy selfsufficiency net of exports at time t for scenario s

$X_{t,s}$: Exports at time t for scenario s

$P_{dom,t,s}$: Domestic energy production at time t for scenario s

$C_{dom,t,s}$: Primary domestic energy consumption at time t for scenario s

The self-sufficiency must be viewed in conjunction with the import dependence ratio, calculated as the import per energy source divided by total demand for the energy source, which provides a clearer picture of where the insufficiency in supply lies, or which among the energy sources fall short of the demand.

Domestic production ($P_{dom,t,s}$) includes the extraction of fossil fuels (oil, gas and coal), traditional and modern biomass as well as the production of non-biomass renewables (e.g. hydro and wind energy). As the REMIND model does not provide any information on biomass extraction, we assume that domestic consumption of biomass equals its domestic extraction. Traditional biomass is mostly consumed in rural areas and thus external trade in biomass is very unlikely. See figures below for shares of energy sources in overall energy production.

Primary domestic energy consumption ($C_{dom,t,s}$) is defined according to the criteria of the Organization for Economic Cooperation and Development (OECD). It refers to energy that has not been subjected to any conversion or transformation process.⁵⁵

⁵⁵ For more information, see <https://stats.oecd.org/glossary/detail.asp?ID=2112>.

Figure 6: Percentage of energy sources in Africa (Reference scenario)

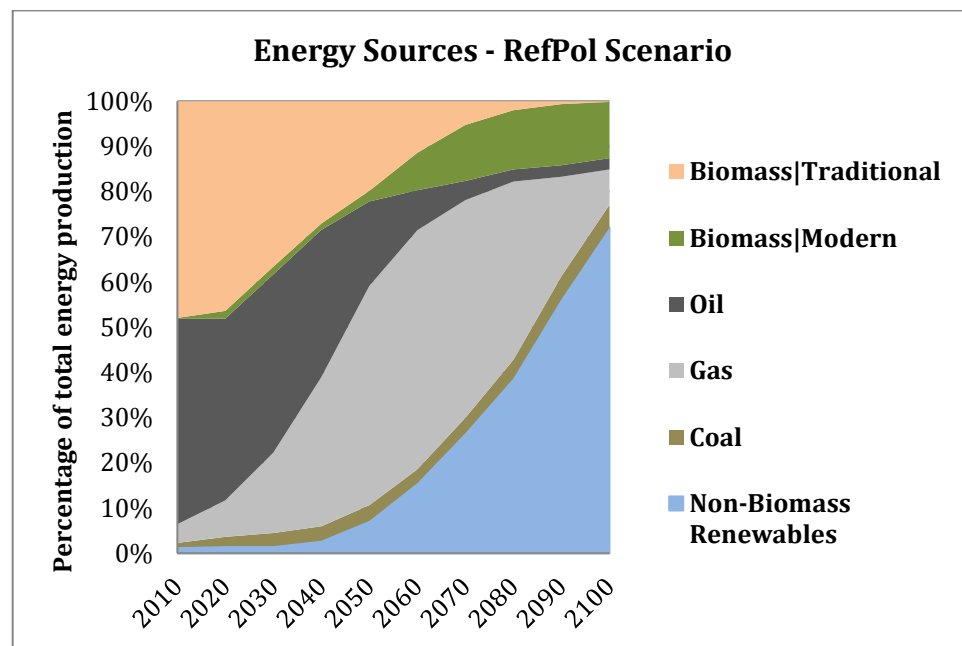


Figure 7 Percentage of energy sources in Africa (2°C scenario)

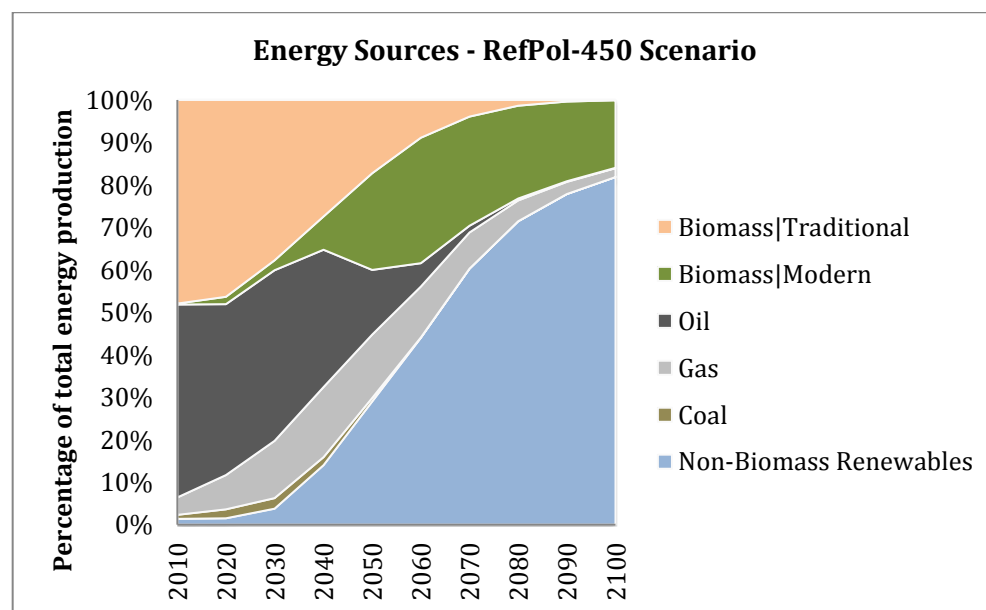


Figure 8 The use of traditional biomass in the REMIND model from 2005-2100 (both scenarios assume the same consumption level).

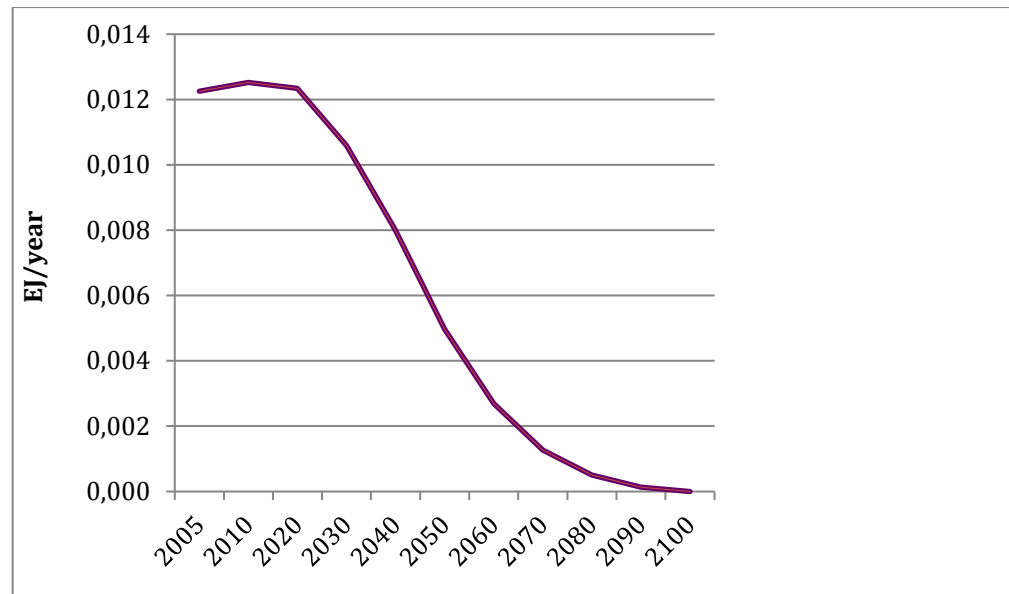


Figure 9: Percentage of energy sources in Africa (Reference scenario)

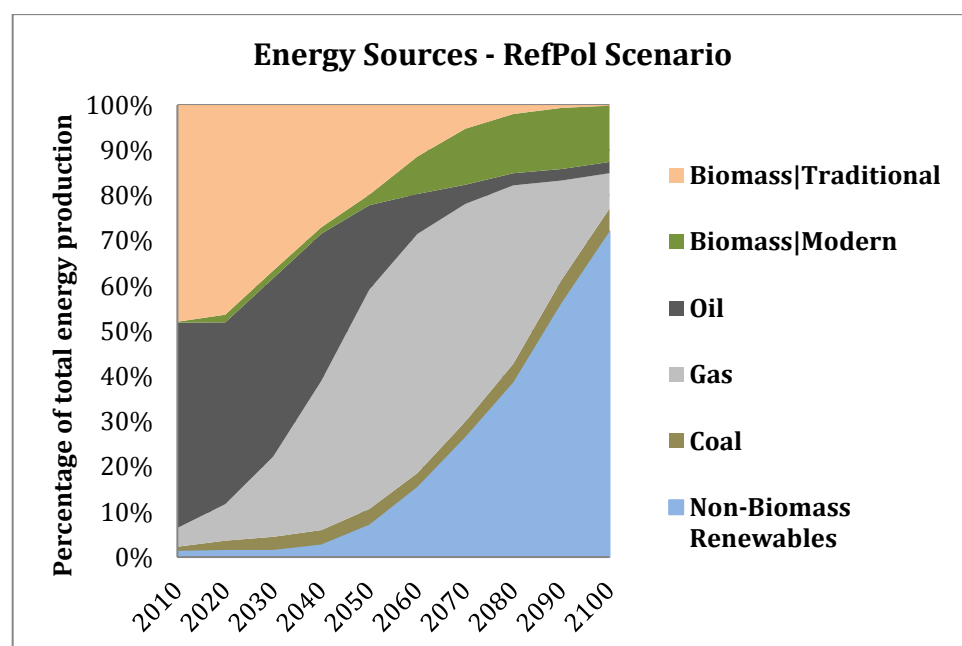


Figure 10 Percentage of energy sources in Africa (2°C scenario)

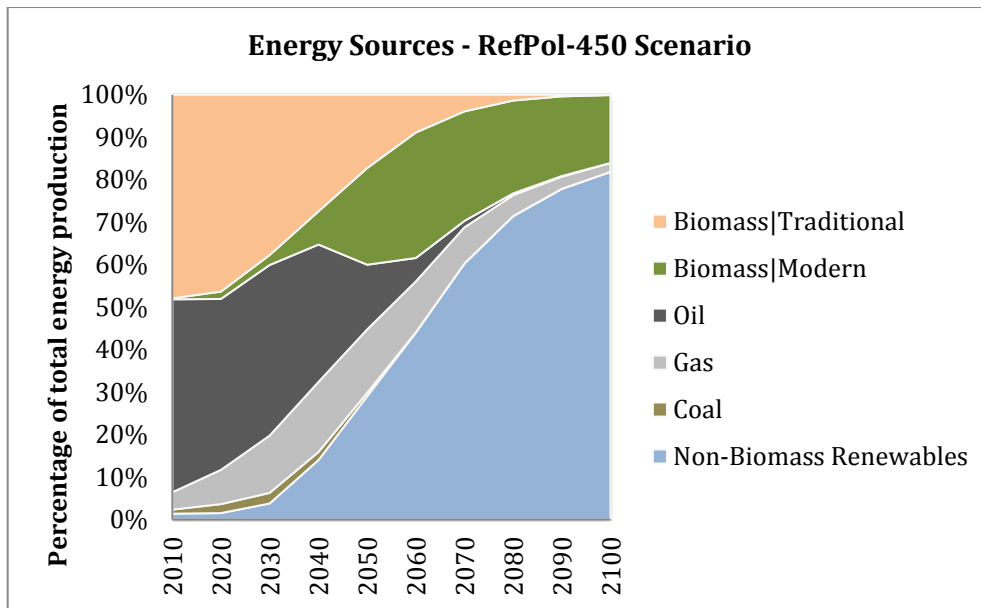
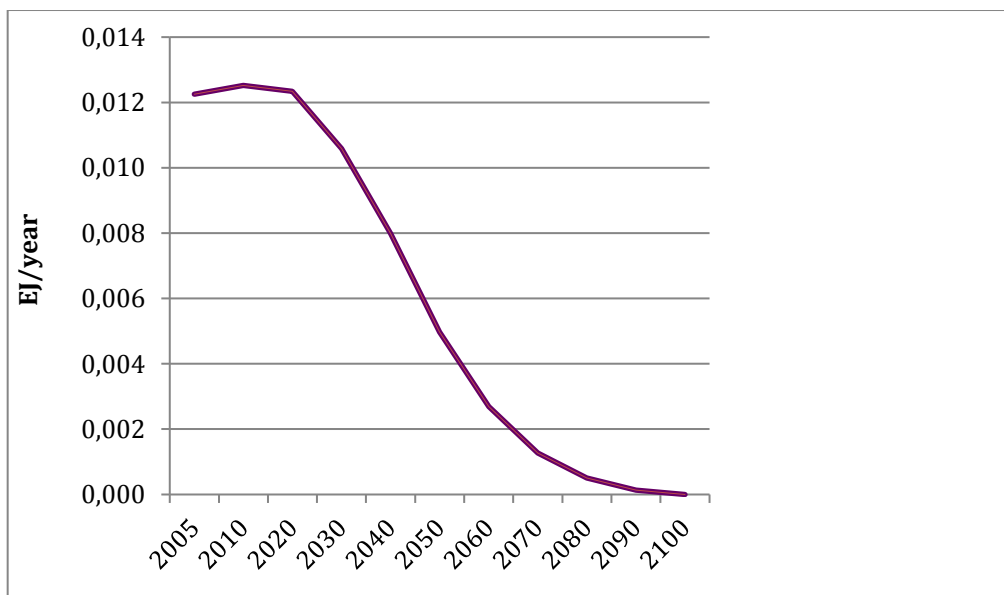


Figure 11 The use of traditional biomass in the REMIND model from 2005-2100 (both scenarios assume the same consumption level)



Detailed results for job creation under 2°C mitigation scenarios

Figure 2 and Figure 3 display the number of workers in construction and O&M for each technology. In the next section we assess job creation related to three key technologies: wind, hydro and solar PV.

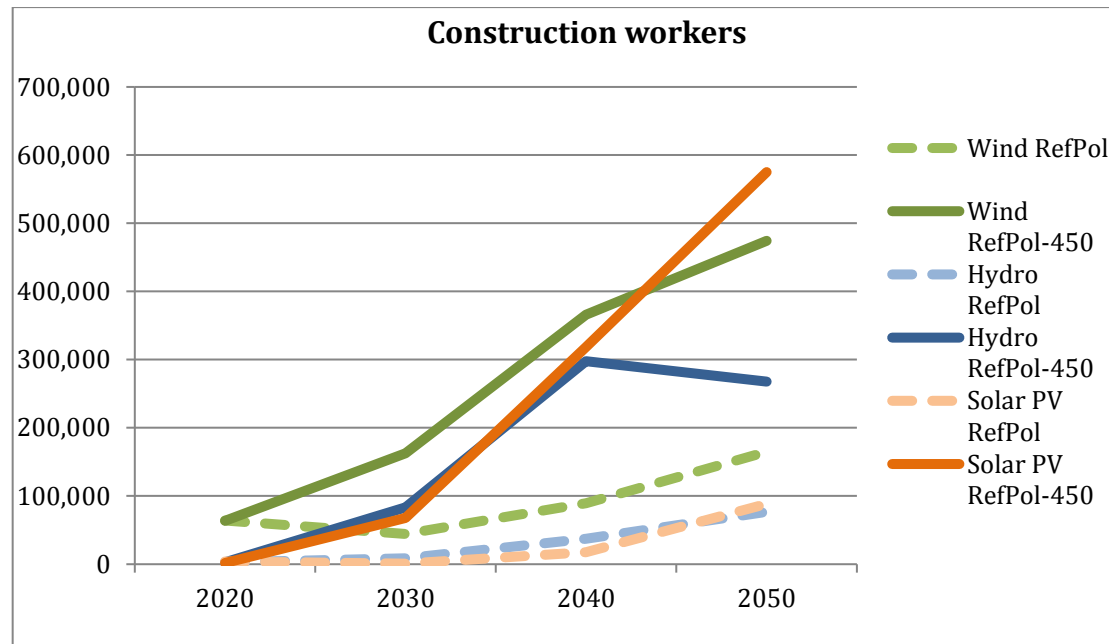


Figure 12 Construction jobs in the wind, hydro and solar sector under two scenarios: RefPol (Reference) and RefPol-450 (2°C scenario).

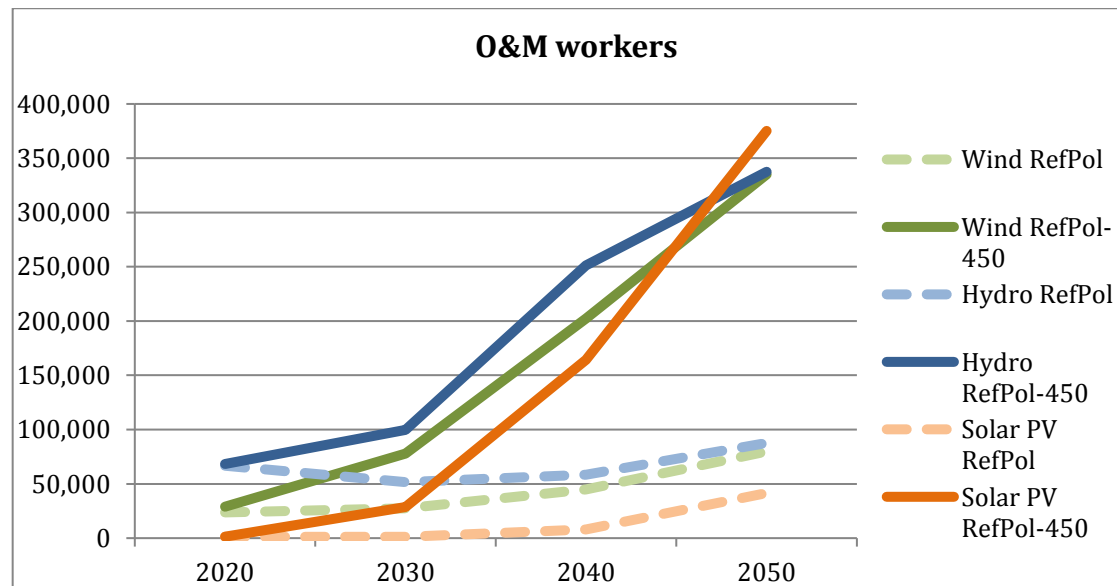


Figure 13 Operation and Management (O&M) jobs in the wind, hydro and solar sector under two scenarios: RefPol (Reference) and RefPol-450 (2°C scenario)

Wind energy

Starting in 2030, construction employment shows a steep increase in the 2°C scenario. Job number estimates based on the Reference scenario increase at a much lower pace. In 2050 between 117,000 and 165,000 (Reference) or between 337,00 and 474,000 (2°C) jobs would be created by wind park construction. In 2050 the number of construction jobs is nearly 3 times higher in the 2°C as compared to the Reference scenario.

For wind energy the growth in O&M employment in the 2°C scenario starts to increase from 2030. The growth rate for the Reference scenario is less steep. In the 2°C scenario between 238,000 and 335,000 people will work in the O&M of wind parks by the year 2050. In terms of the Reference scenario, the job number estimates range between 57,000 and 80,000 people. This means that job creation in the 2°C scenario is more than four times higher than in the Reference.

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