WIDER Working Paper No. 2013/042

Climate uncertainty and economic development

Evaluating the case of Mozambique to 2050

Channing Arndt[1] and James Thurlow[2]

April 2013

Abstract

We apply a probabilistic approach to the evaluation of climate change impacts in the Zambeze River Valley. The economic modeling relies on an economywide modeling approach. Taking a distribution of shocks as inputs, we create hybrid frequency distributions of the potential economic impacts of climate change for Mozambique. The approach identifies an explicit range of potential outcomes and associates a probability with given sets of outcomes. For example, we find that the economy of Mozambique may be up to 13% smaller in 2050 due to the effects of climate change. However, the chance of GDP losses of less than 5% are more than four out of five with about 10% of these outcomes actually positive. Large declines in GDP, defined as a decline greater than 10%, are the result of a dramatic reduction in flood return periods though the probability of large declines is .../

Keywords: Climate change, uncertainty, economic impacts, economywide model, Mozambique
JEL classification: O13, Q54, Q56

---

[1]University of Copenhagen, [2]UNU-WIDER, corresponding author email: arndt@wider.unu.edu

This study has been prepared within the UNU-WIDER project on Development under Climate Change, directed by Channing Arndt, James Thurlow, and Finn Tarp

UNU-WIDER gratefully acknowledges the financial contributions to the research programme from the governments of Denmark, Finland, Sweden, and the United Kingdom.

ISSN 1798-7237 ISBN 978-92-9230-619-9

relatively small at 2.5%. We conclude that this probabilistic approach provides significantly more information to policy makers and productively focuses scientific effort and the agenda for future research.

UNU World Institute for Development Economics Research (UNU-WIDER)
Katajanokanlaituri 6 B, 00160 Helsinki, Finland

Typescript prepared by Lisa Winkler at UNU-WIDER.

1 Introduction

A number of studies have examined a range of important aspects of climate change for the countries within the Zambezi River Valley in Southern Africa. These include the science of climate change, with particular emphasis on developing probabilistic distributions of climate outcomes for the Zambezi River Valley (Schlosser and Strzepek 2013); changes in world prices under alternative emission control scenarios, with an emphasis on agriculture and energy (Paltsev 2012); climate change impacts on agriculture and water resources (Fant et al. 2013); climate change impacts on infrastructure, with an emphasis on roads (Chinowsky et al. 2013); and the implications of sea level rise for coastal surge in the event of a cyclone (Neumann et al. 2013). These studies encompass the principal impact channels anticipated for the Zambezi River Valley to 2050. Each of these studies pays specific attention to climate uncertainty, leading to, for the first time in any region of the world, an integrated distribution of climate and biophysical outcomes in climate sensitive sectors. Following Schlosser et al. (2011), we label these distributions ‘hybrid frequency distributions’ (HFDs).

This paper focuses on Mozambique, which is a representative country within the Zambezi River Valley and is also reasonably typical of low-income agrarian economies in Sub-Saharan Africa. To do this, we employ a dynamic economywide modeling framework with substantial sectoral detail calibrated to a detailed snapshot of the Mozambican economy in 2007. Because the inputs into the economywide model arrive in the form of distributions of shocks, the model outputs generate distributions of variables of interest. For example, we estimate the hybrid frequency distributions (HFD) of average GDP levels over the period 2046-2050 relative to a hypothetical ‘no climate change’ baseline, where historical climate patterns simply repeat themselves. HFDs of economic outcomes provide substantial information about a country’s climate risks, including best and worst case outcomes, where most outcomes are concentrated, the variance and the degree of skewness. Such information can assist in prioritizing adaptation choices and integrating climate and development policies.

The HFDs represent a substantial advance over the current state of the art, where results from a series of independent climates are typically presented. Without a formal attempt to characterize the distribution of future climates, it is not possible to generate a formal distribution of biophysical or economic outcomes. Rather, a selection of climates produces a selection of outcomes. This can provide some useful insight into the ‘true’ future distribution. Under the assumption that each climate and associated biophysical and/or economic outcome is in fact possible, then the ‘true’ future distribution of outcomes must contain the selection of outcomes obtained. Formally speaking, not much more can be said. Without knowing the likelihood of climate outcomes, it is difficult to estimate the opportunity costs of adaptation policies and assess trade-offs between climate and development objectives. This can lead to either inaction or overreaction to climate risks.

The estimation of HFDs on outcomes, in our view, productively shifts the terms of the debate. Suppose that we define the impacts of climate change as being ‘substantial’ if they result in a greater than a 10% reduction in GDP by 2050 relative to a ‘no climate change’ baseline. Earlier analysis has indicated that, for Mozambique, this is possible (Arndt et al. 2011). The current analysis indicates that these outcomes are possible but unlikely. Specifically, our results indicate that the probability of a reduction in GDP of greater than 10% is about 2.5%, or the chances are about one in 40. The clause ‘but unlikely’ adds substantial information of high relevance to decision makers and focuses the research agenda on the likelihood of very strong impacts and the mechanisms that might generate such impacts.

A word on modeling philosophy and interpretation of results is useful at this point. Clearly, when applied to the real world, spurious precision is implied by statements like ‘there is a 2.5% chance that climate change will reduce Mozambican GDP by more than 10% by 2050.’ Much has been said about the complexity of climate change, including its science, biophysics, economics and politics (Emanuel 2007; Tol 2009). Indeed, the HFDs themselves are, in substantial measure, a reflection of ignorance. Accordingly, the distributions are expected to shift and change shape as we learn more.

While complex in the particulars, the general approach taken in this paper is essentially one of trial and error. We clearly cannot conduct controlled experiments on identical but parallel planets, as is the standard for research in, for example, medicine. As such, we are forced to develop simplified representations of our planet that capture its important features and that can be used to provide insights. It is not possible to represent earth in all of its physical, biological, and human complexities. However, it is possible to develop structural representations of these systems and consider how they behave. Drawing on results from biophysical models, this paper creates a plausible simplified world that obeys, among other items, the laws of macroeconomic identities.

The advantages of an integrated structural modeling framework are compelling in that we can subject our simplified world to a vast array of controlled experiments and see how it behaves. The behavior of any element in the system can be compared to its analog in the real world in order to determine how well our simplified world matches what is observed. This sets the stage for the development of better (not necessarily more complex) representations of reality. We can also use the models to gain insights into a future that has not yet arrived. The futures created are based on our best understanding and representation of the actual mechanisms in place. The distributions created are, as a consequence, conditional on our understanding and representation of the climate and climate uncertainty combined with our best understanding and representation of biophysical and economic systems. It is hoped that the results generated both increase our understanding of the implications of climate change and augment our ability to improve this understanding through improvements in our representations of the underlying structural systems.

The remainder of this paper is structured as follows: Section 2 presents background information on Mozambique and Section 3 describes the economywide model employed for the economic impact analysis. Section 4 discusses the shocks drawn from biophysical models, focusing on the case without global climate policy (i.e., the unconstrained emissions scenario). Section 5 presents results with a focus on impacts on the level of real GDP and total absorption (i.e., national welfare) around 2050, and the net present value of these losses until 2050. We take advantage of the structural approach, which allows us to decompose the growth and net present value effects by impact channel and through time. The final section concludes that the probabilistic approach employed offers at least three distinct advantages relative to current practice.

2 Background on Mozambique

2.1 History and context

Mozambique achieved independence from Portugal in 1974. Even by African standards, the country was left with a poor legacy of human development. Despite the exodus of nearly 200,000 Portuguese, representing the vast majority of the country's skilled labor, Mozambique managed to arrest an initially steep fall in GDP in the immediate post-independence period. Following independence, Mozambique opted for a socialist economy, including a collectivization of agriculture. By 1979, it had become clear that the socialist model was failing, particularly in agriculture. Before adjustments could be made, the white regimes in neighboring countries (South Africa and Rhodesia, now Zimbabwe) capitalized on popular discontent and began funding a civil war. The war was brutal and lasted for more than decade. More than a third of the population was displaced and up to 10% of the population was killed. Rural infrastructure, especially schools and health posts, was literally decimated. When peace was finally achieved in 1991, Mozambique had become the poorest country in the world (Tarp et al. 2002).

Since 1992, economic and social conditions have improved dramatically. From a low base, Mozambique has registered some of the world's fastest economic growth rates. A wide array of indicators related to consumption poverty, education, child nutrition, maternal health, assets and mortality have registered improvements (Arndt et al. 2012a). Nevertheless, Mozambique confronts massive development challenges that will take decades to address even assuming the development process proceeds at a reasonably rapid rate. It is a long way up from the poorest country in the world. Mozambique will have to confront these challenges in the context of climate change.

2.2 Economic structure

Tables 1 and 2 provide an overview of Mozambique's economic structure in 2007, which is the base year for our analysis. At market exchange rates prevailing in 2007, Mozambican GDP amounted to almost US$9 billion. Dividing this value by a population of about 21 million yields per capita GDP of about US$420 per annum or somewhat more than oUS$1 per person per day. However, that income is not distributed evenly throughout the population. Not quite 70% of the population is rural and nearly 80% of the population depends upon agriculture for their livelihood. Despite the high concentration of employment in agriculture, the agricultural sector—when broadly defined as crops, livestock, forestry, and fishing—generates only 28% of value added. The low average productivity of agriculture, combined with a lack of employment opportunities in non-agricultural sectors for low skilled labor, implies low incomes and high levels of poverty for most of the population.

Table 1: Mozambique's macroeconomic structure, 2007 [a]

	Value (US$billions)	Share of GDP (%)
GDP (C+I+G+X-M)	8.14	100
Absorption (C+I+G)	8.75	107.6
Consumption (C)	6.51	80.1
Investment (I)	1.28	15.7
Government (G)	0.96	11.9
Exports (X)	2.42	29.7
Agricultural exports	0.30	3.7
Imports (M)	3.04	37.3
Agricultural imports	0.43	5.3
Indirect taxes	0.67	8.2
GDP at factor cost	7.47	91.8
Agriculture	2.11	25.9
Industry	1.22	15.0
Services	4.14	50.9

Note: [a] 2007 Mozambique social accounting matrix converted to US$ at an average market exchange rate of 25.5 MTN/ US$.

Source: authors' calculations using the Mozambique model.

Other salient observations, drawn mainly from Table 2, include the high dependence on metals for export. These include aluminum exports, which are largely an enclave activity with few linkages to other sectors. Electricity, nearly all of which is generated via hydropower, is also a major sector and a significant source of foreign exchange. As a member of the Southern African Power Pool, Mozambique is both a significant importer and exporter of electricity. Importantly, petroleum represents a major import item at about 14% of total imports. In addition, imports of items under the rubric of chemicals often contain items that are high in petroleum content, such as fertilizers and plastics. This high dependence on imported petroleum is a typical feature of many poor African economies. Unlike petroleum, Mozambique's agricultural trade is much closer to being balanced, with a deficit of about US$130 million or 1.6% of GDP (see Table 1). Finally, as a country with a relatively large geographic area, the provision of trading and transport services represents a substantial share of value added. They are also important for exports due to the provision of trade services to countries inland such as Malawi, Zimbabwe, Zambia and South Africa. Overall, Mozambique's economic structure in 2007 is reasonably typical of many low-income African economies.

Table 2: Mozambique's production and trade structure, 2007 [a]

	Share of total (%)			Exports in output (%)	Imports in demand (%)
	Value added	Exports	Imports		
Total economy	100	100	86.1	18.9	26.0
Agriculture	27.7	10.1	7.8	7.7	10.3
Crops	20.5	5.8	7.6	5.8	13.4
Livestock	2.0	0.0	0.1	0.0	2.5
Forestry	3.3	1.0	0.0	6.7	0.0
Fisheries	1.8	3.3	0.0	28.1	0.0
Mining	1.6	9.6	1.5	95.4	75.5
Manufacturing *of which*	15.4	57.2	56.5	36.9	45.5
Foods	4.2	3.1	12.8	3.5	21.1
Metals	7.4	50.7	2.2	100.0	99.3
Petroleum	0.0	0.0	13.9	0.0	100.0
Electricity and water	5.9	9.7	4.4	36.8	24.9
Construction	3.1	0.6	1.6	2.5	7.6
Services *of which*	46.4	13.4	20.6	5.6	10.2
Trade	16.8	5.8	0.0	9.0	0.0
Transport	9.8	5.2	8.8	7.5	14.9
Government	9.6	0.0	0.0	0.0	0.0

Note: [a] 2007 Mozambique social accounting matrix.

Source: authors' calculations using the Mozambique model.

2.3 Natural resource dynamics

It has recently become clear that Mozambique possesses substantial natural resources. The country has just begun to exploit one of the world's largest and highest quality coal deposits. Offshore natural gas has been discovered, with recent estimates pointing to substantial economically exploitable reserves. While it is clear that development of these hydrocarbon resources will proceed and that hydrocarbons will serve as a source for GDP growth and foreign exchange, vast uncertainties characterize the actual path that will be followed. The exploitation of coal is constrained principally by insufficient rail and port transport infrastructure (Rosenfeld 2012). Until adequate transport infrastructure is in place, coal exports will be small with negligible economic impacts. Gas exploitation may be even further into the future as the process of offshore extraction is complex and ready markets are not available for raw natural gas. The gas must be liquefied, piped to a regional source (South Africa) or used essentially on the spot for electricity generation or industry.

Coal and gas exploitation are both highly capita-intensive activities. Due to skills shortages and lack of capital, these extraction activities will rely to a large degree on foreign skilled labor and foreign capital. These features strongly limit the economic linkages between these sectors and the rest of the economy. Future tax revenues, alongside the potential for some new infrastructure, represent the primary linkage to the domestic economy. Unfortunately, the net benefits of these revenues to the Mozambican economy depend to a considerable degree on the behavior of aid donors. Mozambique currently receives approximately US$1.3 billion in foreign assistance per annum (OECD/DAC 2012). It is possible that natural resource revenues will simply displace foreign assistance leaving the country with no net gain in resources over the medium-term.[1]

These developments will proceed independently of climate change impacts (though not of global mitigation policy). As the focus of this analysis is on climate change impacts under the assumption of unconstrained emissions, we opt to avoid the complications of projecting the impacts of natural resource exploitation. Instead, we assume that net foreign resource availability from aid, natural resource rents, or other capital inflows grows to about US$3 billion in real terms by 2050. While well below some of the more optimistic projections of future natural resource rents accruing to the economy, the number is not implausible. Usefully, the assumption maintains Mozambique as a reasonably typical poor African economy rather than overlaying climate change impacts on top of a transition from a poor economy to a resource-rich economy.

On the other hand, we do track projections of increased hydropower production, based principally on investments in new large dams to be constructed on the Zambezi, since these investments are clearly climate-sensitive. Investment plans including the financial contributions to the government and repatriation of profits by foreign investors are drawn from Electricidade de Moçambique (2012).

3 Economywide model

The impact of climate change is simulated using a dynamic computable general equilibrium (CGE) model. These models have features making them suitable for this analysis. First, they simulate the functioning of a market economy, including markets for labor, capita,l and commodities. Second, the structural nature of these models permits consideration of new phenomena, such as climate change. Changes in economic conditions are mediated through prices and markets allowing for a degree of endogenous adaptation. For example, if dryer conditions result in reduced hydropower exports, the real exchange rate will adjust in order to conserve foreign exchange by reducing imports and generate foreign exchange by increasing exports from other sectors. Third, these models assure that all economywide constraints are respected. This is critical discipline that should be imposed on long-run projections, such as those necessary for climate change. Finally, CGE models contain detailed sector breakdowns and provide a ‘simulation laboratory’ for quantitatively examining how various impact channels influence the performance and structure of the economy.

In CGE models, economic decision-making is the outcome of decentralized decision-making by producers and consumers within a coherent economywide framework. A variety of substitution mechanisms occur in response to variations in relative prices, including substitution between labor types; capital and labor; imports and domestic goods; and between exports and domestic sales.

The Mozambique CGE model contains 31 activities/commodities and four regions (north, center, south and an urban zone). Production from ten agricultural activities is divided by region. This is important for the analysis of climate change as, for example, growing

---

[1] Foreign aid flows would eventually dissipate of their own accord as Mozambique develops, and so natural resource revenues would eventually become additional.

conditions might improve (deteriorate) in the South while deteriorating (improving) in the north. Non-agricultural activities are assumed to be produced in the single urban zone. There are four primary product processing activities that capture linkages between primary product production and related manufacturing. Seven basic factors of production are identified: four types of labor (uneducated and those with primary, secondary, and tertiary levels of education), agricultural land, livestock, and capital. The land and livestock are distributed across the three regions of Mozambique (north, center and south). This detail captures Mozambique's economic structure and influences model results.

The model includes three macroeconomic accounts: government balance, current account, and savings-investment account. In order to bring about balance in the macro accounts, it is necessary to specify a set of 'macroclosure' rules, which provide a mechanism through which balance is achieved. A balanced closure is assumed for the savings investment and government accounts. This closure maintains constant the share of investment and government in nominal absorption (i.e., C+I+G from Table 1). To balance savings with investment, households' and enterprises' marginal propensities to save adjusts proportionally. In the government account, the fiscal deficit is assumed to remain unchanged, with government revenues and expenditures balanced through changes in direct tax rates to households and enterprises. For the current account, a flexible exchange rate adjusts in order to maintain a fixed level of foreign savings (i.e., the external balance is exogenously specified in foreign currency terms). Labor is assumed to be mobile across sectors and fully employed. The assumption of full employment is consistent with widespread evidence that, while relatively few people have formal sector jobs, the large majority of working age people engage in activities that contribute to GDP (Jones and Tarp 2012).

The CGE model is calibrated to a 2007 social accounting matrix (SAM), which was constructed using national accounts, trade and tax data, and household income and expenditure data from a nationally representative household survey. Trade elasticities are cross-country estimates from Dimaranan (2006). The model is calibrated so that the initial equilibrium reproduces the base-year values from the SAM.

The features described above apply to a single-period 'static' CGE model. However, because climate change will unfold over decades, the model must be made 'dynamic' through a set of accumulation and updating rules (e.g., investment adding to capital stock; labor force growth by skill category; productivity growth). In addition, expectation formations must be specified. Expectations are a distinguishing feature of macroeconomic models. In our CGE model, a simple set of adaptive expectations rules are chosen so that investment is allocated according to current relative prices under the expectation that the climate realization in the upcoming year will be an average of recent experience. A series of dynamic equations 'update' various parameters and variables from one year to the next. For the most part, the relationships are straightforward. Growth in the total supply of each labor category and land is specified exogenously, sector capital stocks are adjusted each year based on investment, net of depreciation. Factor returns adjust so that factor supply equals demand. The model adopts a 'putty-clay' formulation, whereby new investment can be directed to any sector in response to differential rates of return, but installed equipment remains immobile (e.g., a grain mill cannot be converted into a truck). Sector- and factor-specific productivity growth is specified exogenously. Using these simple relationships to update key variables, we can generate a series of growth trajectories, based on different climate scenarios. Further details on the core model employed can be found in Diao and Thurlow (2012).

Finally, the relationships embodied in the road infrastructure model discussed in Chinowsky et al. (2013) are incorporated directly into the dynamic updating of the CGE model. The road model tracks road network length for each of the four regions in the model. Direct incorporation of the road network model permits consideration of two feedback effects. First, the road budget can expand or contract with the overall government budget, which is tracked by the model. Second, there is considerable evidence that improved transport networks spur production and productivity growth (see Arndt et al. 2012b for a review of this literature). With the road model incorporated into the CGE model, some mild positive and negative feedbacks are captured. Specifically, favorable growth conditions expand government budgets which permit an expanded road network which provides a small boost to productivity which in turn supports continued growth. The extent of these feedbacks is fairly mild, at least out to 2050, and is analyzed in Arndt et al. (2012b). Complete details on the road model as incorporated in the CGE model can be found in Chinowsky and Arndt (2012).

4 Climate change scenarios

Table 3 summarizes all the scenarios considered in the analysis. We discuss the scenarios and present relevant shocks in turn.

Table 3: Scenarios

Scenario name		Description
1	Baseline	Dynamic path with constant world prices and historical climate variability that establishes baseline (no climate change) implications for agriculture, hydropower generation, and road network extent
2	World prices	*Baseline* + world price changes to 2050 as projected by Paltsev (2012) for the unconstrained emissions scenario
3	Agriculture	*World Prices* + climate change implications for agricultural production as discussed by Fant et al. (2013) are introduced. Climate uncertainty is captured through the use of the 426 climates selected by Arndt et al. (2012c)
4	Roads	*Agriculture* + implications for roads
5	Electricity	*Roads* + implications for hydropower
6	Sea level rise	*Electricity* + implications of sea level rise
7	Cyclone	*Sea Level Rise* + probabilistic cyclone strike. This is the final scenario incorporating all impact channels

Source: authors' compilation.

4.1 Baseline

The objective of the Baseline scenario is to set plausible values for general economic growth determinants. Unless these determinants are affected by climate change, their values remain constant across all scenarios. By holding all determinants constant, except those affected by climate change, the implications of climate change for economic growth can be inferred. In the baseline, total factor productivity (TFP) growth is initially set at 2% per annum for agriculture and at 3% per annum for non-agriculture. The TFP growth rate is assumed to decline linearly with time reaching values of 1.6% and 2.6% per annum for agriculture and non-agriculture, respectively, by 2050.

The growth rates for labor and land are set exogenously. The stocks of uneducated, primary, secondary, and tertiary labor grow at 1.2%, 1.4%, 1.7%, and 2.2% per annum respectively. These rates are consistent with population growth and rising educational attainment. Growth in land begins at 1% per annum in 2007. This rate of growth declines linearly to zero by 2050. A final factor of production, capital allocated to hydropower production, is also set exogenously. As indicated, hydropower production is already substantial and is expected to grow with a variety of planned hydroelectric projects along the Zambezi River. The capital allocated to hydropower is assumed to nearly quadruple by 2050, with the majority of newly installed capacity in place by the mid-2020s (Electricidade de Moçambique 2012).

As indicated in Table 3 and discussed in Fant el al. (2013), historical climate variability is introduced into the baseline path by assuming that 40 years of historical climate repeats itself over the period 2011 to 2050. These climate variations affect agricultural and hydropower output. In addition, the economic and climate outcomes establish a baseline level for road network expansion out to 2050. These assumptions combine to result in a GDP growth rate of about 5% per annum between 2007 and 2050. In per capita terms, this translates to a growth rate of about 3.6% per annum. Over this period, the share of crops and livestock in GDP declines from about 23% (see Table 2) to about 10% consistent with normal patterns of growth and structural change.

4.2 World prices

While projecting future prices is inherently tricky and subject to considerable error, the world price projections developed by Paltsev (2012) are incorporated into the projections. This is done because world price changes and climate change will interact. For example, Paltsev projects a 23% increase in the real price of agricultural products by 2050 under the assumption of unconstrained emissions. With these world price increases, the welfare implications of productivity declines in agriculture may be magnified because the option of importing food in order to make up for these shortfalls is no longer as attractive. In addition, petroleum prices are projected to nearly triple by 2050 under unconstrained emissions. As noted, Mozambique, like the vast majority of other least developed countries, currently imports nearly all hydrocarbons consumed and hydrocarbons, particularly petroleum, represent a substantial import item. Rising prices for fuels increase the importance of activities that produce exports or substitute for imports. If climate change reduces production of an import export item, such as hydropower, rising fuel prices will tend to magnify the economic importance of this effect.

4.3 Agriculture

In this scenario, shocks to crops and livestock are applied on an annual basis. As presented in Fant et al. (2013) the majority of climate outcomes lead to declining yields for rain-fed crops, though both positive and negative crop yield implications are possible for nearly all crops under alternative climate projections. By around 2050, across all climate scenarios, yields are expected to decline by about 3-4% on average, although average declines of greater than 10% are possible in specific climate scenarios.[2] A recent meta-analysis of crop yield impacts in Africa and Asia by Knox et al. (2012) provides a useful point of comparison. The estimates

---

[2] Exact figures depend upon the weighting scheme employed for yields across crops and regions.

generated by Fant et al. (2013) fit comfortably within the range of impacts by 2050 reported by Knox et al. (2012). While within the range, the estimates of Fant et al. (2013) tend on average to be slightly more optimistic than the median reported by Knox et al. (2012) for 2050.

As indicated, land and capital allocations within agriculture are determined within the CGE model on the basis of expected yields and prices. The climate realization then causes deviations (both positive and negative) from this expected level. It is important to highlight that, in the model, the underlying rate of technical advance in agriculture is unaffected by climate change. While unfavorable growing conditions result in production declines, the underlying productive capacity of the land (when complemented with appropriate levels of labor, capital, and purchased inputs) is assumed to be unaffected. Consequently, production levels rebound under favorable climate outcomes (Benson and Clay 1998).

4.4 Roads

As explained in Chinowsky et al. (2013), changes in temperature, precipitation, and the frequency/severity of flooding events can have strong impacts on road infrastructure. Events that destroy infrastructure, such as fast moving floods across roads, tend to reduce economic growth (Noy 2009). Floods eliminate both private and public capital. With respect to roads and in the absence of insurance mechanisms,[3] budget that would have been directed towards expanding the quality and density of the network must be redirected to replacing the infrastructure lost. The result of heightened flood frequency/intensity is a smaller and lower quality road network. Following Arndt et al. (2012b), we assume that sector specific productivity growth (excluding hydropower and aluminum production) is proportional to the ratio of road network length relative to the baseline. So, if the rate of productivity growth in non-agricultural sectors is 2.6% per annum in 2049 in the baseline and the size of the road network in climate scenario *i* is 95% of the baseline, then productivity growth in non-agricultural sectors in climate scenario *i* in 2049 is assumed to be 2.6*.95= 2.47%.

As discussed in Fant et al. (2013), increases in runoff are projected to dramatically reduce return periods on major flood events in Mozambique by the 2040s. Implications in the 2010s and 2020s are much more evenly distributed with many scenarios implying reduced frequency/intensity of flooding events and hence faster accumulation of infrastructure and marginally faster productivity growth than in the baseline.

4.5 Energy

Similar to agriculture, the application of shocks to hydropower production in the CGE model is straightforward. Proportional shocks are applied. If the hydropower modeling indicates that actual production in the year *t* is 95% or 105% of the expected level due to decreased or increased river flow, then hydropower production is augmented or reduced accordingly. The shocks employed are derived from Fant et al. (2013). It is useful to point out that, in many sectors, deviations from historical climate norms are frequently expected to have negative impacts because systems are designed for a given climate. It is possible that the shift in climate favors the existing system such as a climate realization that produces fewer extreme flooding events or more reliable rainfall during the growing season in water stressed zones.

---

[3] Agents in a country can explicitly insure against natural disasters. Due to integrated financial markets, large-scale natural disaster may provoke an inflow of capital in the form of insurance payments. In developing countries, this mechanism is unlikely to be very important though the international community may respond with increased foreign assistance. The model employed for this analysis assumes no insurance mechanisms.

However, particularly in the absence of adaptation, the shift in climate will often not favor the existing system leading to an expectation of negative impacts. This is much less the case for hydropower, which depends mainly on river flow. As river flow may increase or decrease, expectations on the sign of hydropower impacts are not possible a priori.

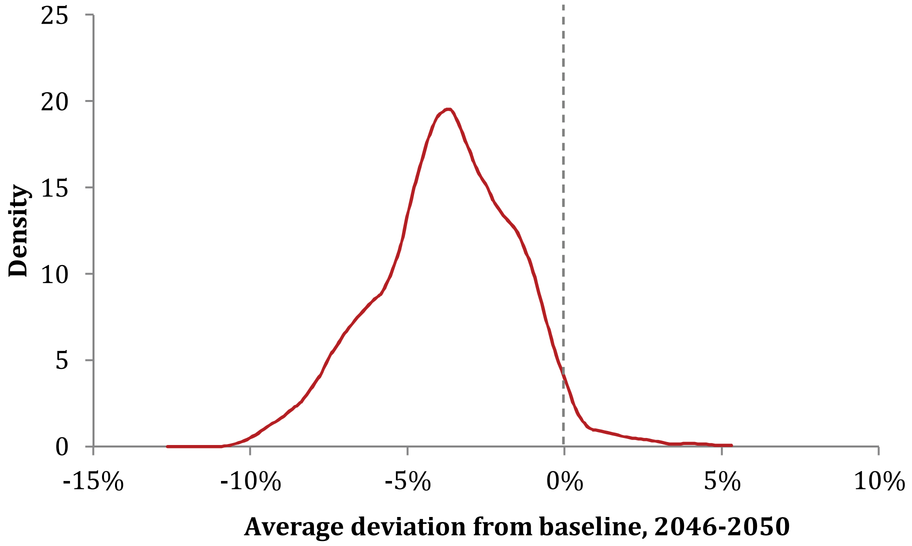
4.6 Sea level rise and cyclones

Unlike all preceding shocks, sea level rise and cyclones are uniformly negative shocks for growth and development. Sea level rise is assumed to reduce the area of arable land available for production as coastal arable land becomes submerged. Cyclones are more complex but also uniformly negative (at least as modeled here). As explained in Neumann et al. (2013), sea level rise is presumed to provide an advanced starting point for the storm surges associated with cyclones. Similar to Neumann et al. (2013), we assume that climate change does not increase (or decrease) the frequency or severity of cyclone strike. To simplify the economic modeling, we focus uniquely on the marginal impact of cyclones due to sea level rise as the other effects of cyclones, such as wind damage, are assumed to be constant between the climate change and no climate change scenarios. For each year in each climate, a random cyclone is drawn from the distribution provided by the return periods. The marginal impact of the cyclone is then calculated based on linear sea level reaching an increase of about 38 cm by 2050. Because the large majority of capital is located in Maputo, where the marginal impact of sea level rise on cyclone strike is relatively mild in terms of the value of capital at risk, and/or away from coastal zones, where there is no risk associated with storm surge, the marginal impacts on capital stocks even for large storms in 2050 are small, about 0.2% of total capital in the economy lost. At the same time, cyclone strikes are fairly regular events in Mozambique. So, the combined effects of cyclones and sea level rise lead to small but consistent reductions in land and capital stocks.

5 Simulation results

We begin by focusing on impacts on agricultural value added when only climate change impacts for crop yields are considered (scenario Agriculture). Figure 1 shows the estimated HFD of impacts on agriculture when the definition of agriculture is restricted to crops and livestock. The horizontal axis reports the percentage change in the average of value added in agriculture over the period 2046-2050 relative to the baseline. The vertical axis reports the estimated density, which is a measure of likelihood. The mode of the distribution centers around about a 4% decline in total agricultural value added. Declines of up to 10% are possible. It is also possible, but not likely, that agricultural value added actually grows. The probability of a gain in agricultural value added as a result of climate change induced crop yield effects alone is small at about 3%.

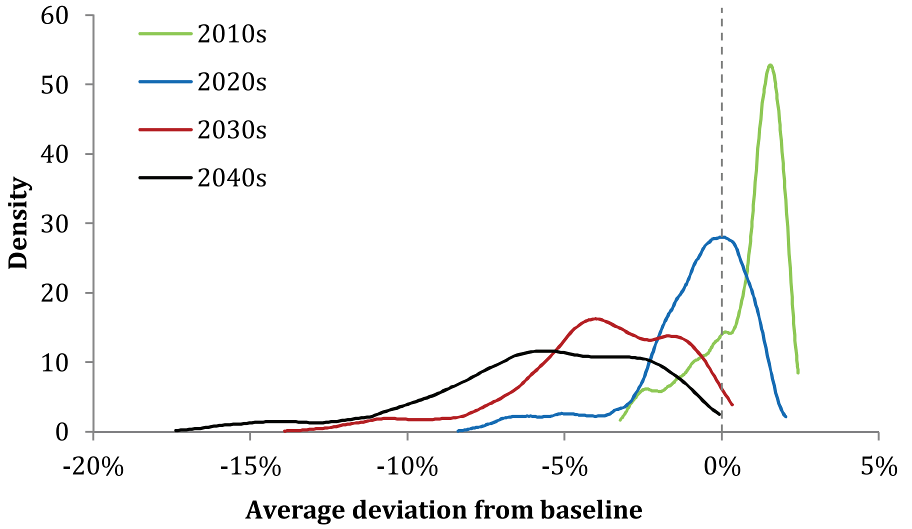
Figure 1: Value added in agriculture relative to the baseline for the Agriculture scenario, 2046-2050



Source: results from the Mozambique model.

The second simulation scenario involves roads. Figure 2 uses the same graphical format to consider road network length by decade. We elect to present the total effect on road network length from the final Cyclone scenario. The very large majority of effects on roads arise from the direct shocks imposed in the roads scenario. In the 2010s, when very few climate change impacts are present, the median impact on roads is actually slightly positive. However, the average or expected impact is almost exactly zero due to the presence of a negative tail in the HFD. As time progresses, the mode of the distribution shifts to the left and the distribution becomes progressively skewed to the left. By the 2040s, the average length of the road network is always smaller than in the baseline. Strongly negative outcomes in terms of road network length are associated with dramatic reductions in the return periods for major flood events.

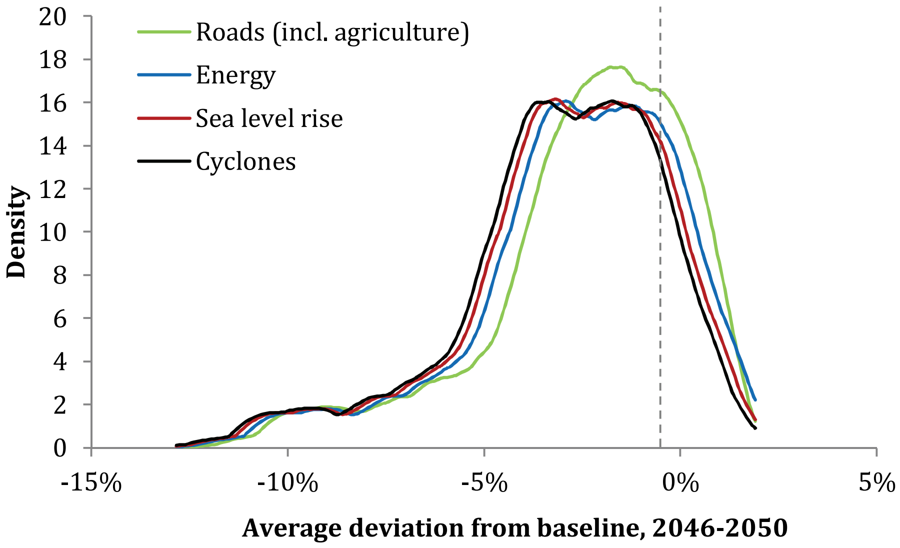
Figure 2: Impacts on average road network length by decade for the Cyclone scenario



Source: results from the Mozambique model.

Figure 3 illustrates the implications of all shocks considered for total GDP at factor cost. The horizontal axis reports the percentage change in the average of total value added over the period 2046-2050 relative to the baseline, and the vertical axis reports the density or measure of likelihood. As emphasized in Table 3, the scenarios are cumulative with climate shocks progressively added but never removed. A large number of observations are possible from Figure 2.

Figure 3: Percent deviation of GDP at factor cost relative to baseline, 2046-2050



Source: results from the Mozambique model.

The vertical dotted line shows the mean effect of the crop effects from the scenario Agriculture on total value added (the HFD for the scenario Agriculture is omitted because of limited variation around the mean). The impact is a bit more than 0.4% of GDP, which is sensible given that the impacts on agricultural value added alone are about 4% and the agricultural share of GDP is about 10%.

The next effect modeled is Roads scenario. As Figure 2 indicates, this is a major potential source of impact. The effect of roads is to expand the range of potential impacts dramatically. The large bulk (about 86%) of potential outcomes, considering the combined effect of Agriculture and Roads only, lie between about -5% and +2% of GDP. There are no strongly positive outcomes; however, for the first time, strongly negative outcomes are introduced with about 14% of outcomes stronger than -5% of GDP and about 1.5% of outcomes stronger than -10% of GDP. So, while the expected impact of climate change in the scenario Roads is not enormous at about -2.4% of GDP, the road channel substantially increases the range of potential outcomes.

Energy, or the impacts on hydropower, is the next effect added. As discussed in Fant et al. (2013), impacts on hydropower in Mozambique are negative on average. The shape of the distribution of GDP outcomes is largely similar to that of Roads but with a small shift to the left. The mean climate change impacts increases by not quite 0.3% of GDP bringing the mean total impact up to about -2.7% of GDP.

As discussed above, the effects of sea level rise and cyclones are uniformly negative. The distribution again shifts to the left by about 0.2% of GDP for each effect. The expected loss of GDP is thus about -3.1% when all impact channels are included (e.g., the scenario Cyclones). As emphasized in the introduction, this mean disguises a great deal of information that the hybrid frequency distributions reveal. In particular, impacts greater than 10% of GDP in about 2050 are possible but unlikely with about a 2.5% probability of occurrence. The majority of outcomes, about 73%, lie within 0% and 5% of GDP. The probability of positive GDP outcomes by 2050 is small but non-negligible at slightly less than 9%.

Overall, more than four out of five outcomes imply losses less than 5% of GDP. In per capita terms, GDP losses of less than 5% by about 2050 imply a growth delay that of two years or less. In other words, if the economy is 5% smaller in 2050 as a result of climate change, the economy could be expected to fill that gap by about 2052. Viewed through this optic, climate change does not appear to exert a large influence at least out to 2050. However, in many scenarios, the people of Mozambique, who are already among the poorest in the world, are experiencing sustained losses for long periods as a result of climate change (even when the analysis extends only to 2050).

These sustained losses can be captured via a calculation of the net present value of GDP losses. Before proceeding with the net present value of losses results, one caveat is in order. In specifying a baseline path and holding that path constant with respect to factors not related to climate change, the intention is to isolate climate change impacts. If climate change impacts are largely proportional (which is the way that they are modeled here), then calculations such as those presented for the size of the economy under climate change relative to the baseline path should not be highly sensitive to the rate of economic growth specified in the baseline path. In other words, if a given climate future causes GDP to be 5% smaller in 2050 relative to the baseline path when the GDP growth rate in the baseline path is assumed to be 4%, a very similar result should be expected if the GDP growth rate is set at 5% or 6% in the baseline path. The result is mainly insensitive to the baseline path, which is desirable.

Unfortunately, this property does not hold for net present value calculations when climate change impacts are proportional. Let us continue with the example of an economy that is 5% smaller in 2050 as a result of climate change. If the baseline path growth rate is 4% per annum, the initial size of the economy in 2007 is US$9 billion, and climate change impacts arrive at 5% of GDP in 2050 at a linear rate through time, then the net present of losses imposed by climate change amount to about US$7.2 billion assuming a 5% discount rate. If the baseline growth rate is increased to 6% per annum and all other assumptions remain constant, then the net present value of losses increases by almost 75% to nearly US$12.5 billion. In the latter case, the climate change impacts appear to be a lot worse, but the only thing that has changed is the underlying rate of growth specified in the baseline path, which is entirely unrelated to climate change. This is not problematic if the baseline path growth rate is held constant, which is the case here. However, this property of net present values does have implications for comparisons across multiple studies where baseline path growth rates are likely to differ, perhaps considerably.[4]

Having stated this, the net present value of losses is shown by scenario in Figure 4. A discount rate of 5% is applied. Table 4 complements Figure 4 by showing the probability of falling into one of four categories in terms of losses for each scenario as well as the mean loss by scenario. Overall, the support of the distribution of the net present value of GDP changes imposed by climate change is very wide running from a US$15 billion loss to a US$5 billion gain. This compares to an economy of about nine billion in 2007. While the variance

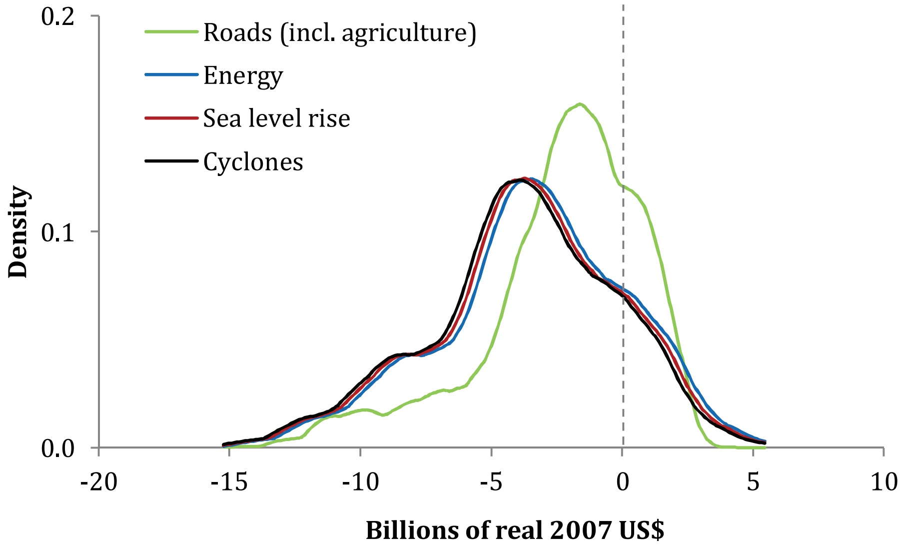
---

[4] Net present value calculations will also be sensitive to the initial size of the economy for similar reasons.

expanding effect of the Roads scenario shown in Figure 3 remains present in Figure 4, the impact of the consistency of losses imposed in the Energy, Sea Level Rise, and Cyclone scenarios is brought into sharper relief in Figure 4.

Table 4 provides further insight. The probability of a gain in net present value terms, at about 15%, is about six percentage points larger than the probability of a larger economy in 2050. This occurs because climate change impacts may be positive for an extended period before turning negative in the late 2040s. This compilation of effects through time combined with the effect of discounting on later period losses explains the increased probability of gain in net present value terms. While positive outcomes are present, the large bulk of outcomes are negative with many of them strongly so. The probability that total losses to 2050 will exceed US$5 billion is more than one in three. The probability of losses greater than US$10 billion (or more than the size of the total economy in 2007) is about 6%. Viewed in this way, the losses imposed by climate change are significant.

Figure 4: Net present value of GDP losses from 2010 to 2050 by scenario



Source: results from the Mozambique model.

Table 4: Mean net present value of losses and probability of loss by category

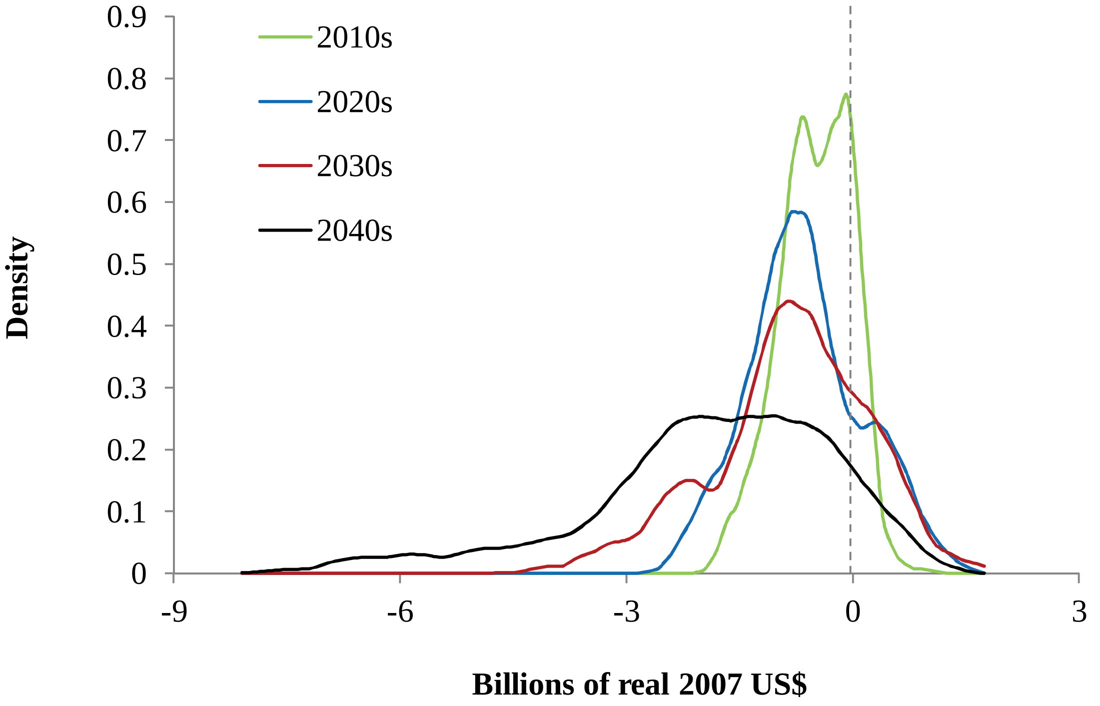
	Agriculture	Roads	Energy	SLR	Cyclone
Mean (2007 US$ billion)[a]	-1.19	-2.34	-3.42	-3.66	-3.85
Prob. loss > 10 Billion	0.0	3.6	5.1	5.7	6.2
Prob. loss 5-10 Billion	0.0	12.3	24.4	26.4	28.0
Prob. loss 0-5 Billion	91.9	60.7	51.9	51.3	50.6
Prob. of gain	8.1	23.5	18.5	16.7	15.3

Note: [a] Values are real 2007 US$ and a discount rate of 5% is applied.

Source: results from the Mozambique model.

Finally, Figure 5 presents the net present value of losses by decade. The graph points to progressively stronger impacts through time. Despite the 5% discount rate applied, the 2040s generate on average the strongest climate change impacts. As might be expected, the variance of impacts also increases with time. The range of outcomes in the 2010s is small relative to later decades. The mainly negative impacts in 2010s stem primarily from agriculture and hydropower shocks (not shown). Road shocks are typically positive in the 2010s (see Figure 2); however, during the 2010s, insufficient time has passed for the road shocks to cumulate into meaningful differences in road stocks or productivity levels. Hence, the effect of roads in the 2010s is positive but small and fails to outweigh the negative implications from agriculture and hydropower. The distributions then become progressively wider culminating in the distribution of possible outcomes in the 2040s, which is by far the widest. Recalling that the baseline growth rate is about 5% or very similar to the discount rate, Figure 5 illustrates that climate change shocks are tending to become larger with time relative to the size of the total economy.

Figure 5: Net present value of GDP losses by decade for the Cyclone scenario



Source: results from the Mozambique model.

6 Conclusion

The paper adopts a probabilistic approach to assessing climate change risks and vulnerabilities. This approach has at least three principal advantages. First, it provides a much more comprehensive and useful picture for policy makers. To date, analysts have been forced to state that climate change impacts might be large, small, or even positive without any formal mechanism for estimating the probability of a given outcome. In addition, the probabilistic approach provides much more detailed insight into the importance of various impact channels including the possibility of capturing interactions between impact channels across the range of potential future climates.

Second, the structural probabilistic approach pursued here provides a more effective guide to future research. There are clearly inherent and irreducible uncertainties associated with climate change. We must confront a range of potential future climate outcomes. In this environment, we need to know whether a revised or improved approach to representing a climatic, biophysical, or economic phenomenon shifts or reshapes the distribution of results. For example, with the approach employed here, a formal mechanism exists for arguing that the negative tail of economic outcomes should be more or less pronounced than presented here for reasons that can be explicitly related to the representations of the climatic, biophysical, and economic systems involved.

Third and relating to future research, the probabilistic approach provides a more holistic and comprehensive approach for evaluating adaptation options. Adaptation policy is constrained by uncertainties concerning the exact nature of climate change. Most obviously, taking steps to adapt to a dryer future when a wetter future is possible, risks not only wasting resources but being counterproductive. The probabilistic approach captures these possibilities and puts the focus squarely on flexible and/or robust options. In poor countries, these options should contribute to the realization of development objectives across a range of potential climates. Finally, the probabilistic approach provides a formal means for considering the gains associated with mitigation policies both in terms of mean outcomes and in terms of reduced probability of strongly negative outcomes.

References

Arndt C, Hussain MA, Jones S, Nhate V, Tarp F, Thurlow J (2012a) Explaining the evolution of poverty: the case of Mozambique. Am J Agr Econ 94(4):854–872

Arndt C, Strzepek K, Tarp F, Thurlow J, Fant C, Wright L (2011) Adapting to climate change: an integrated biophysical and economic analysis for Mozambique. Sustain Sci 6(1):7–20

Arndt C, Chinowsky P, Strzepek K, Thurlow J (2012b) Climate change, growth and infrastructure investment: the case of Mozambique. Rev Dev Econ 16(3):463–475

Arndt C, Fant C, Robinson S, Strzepek K (2012c) Informed selection of future climates. Working paper 2012/60. Helsinki: UNU-WIDER

Benson C, Clay E (1998) The impact of drought on Sub-Saharan African economies: a preliminary examination. Technical Paper No. 401, World Bank, Washington, DC

Chinowsky P, Arndt C (2012) Climate change and roads: A dynamic stressor-response model. Rev Dev Econ 16(3):448–462

Chinowsky PS, Schweikert AE, Strzepek NL, Strzepek K (2013) Infrastructure and climate change: impacts and adaptations for the Zambezi River Valley. Working paper 2013/041. Helsinki: UNU-WIDER

Diao X, Thurlow J (2012) A recursive dynamic computable general equilibrium model. In: Diao X, Thurlow J, Benin S, Fan S. Strategies and priorities for African agriculture: economywide perspectives from country studies. International Food Policy Research Institute, Washington DC

Dimaranan, BV (2006) Global trade, assistance, and production: the GTAP 6 Data Base. for Global Trade Analysis, Purdue University

Electricidade de Moçambique (2012) CESUL feasibility study. Internal report. Maputo

Emanuel, KA (2007) Phaeton’s Reins - the human hand in climate change. Boston Rev January/February:7-13

Fant C, Gebretsadik Y, Strzepek K (2013) Impact of climate change on crops, irrigation and hydropower in the Zambezi River Basin. Working paper 2013/039. Helsinki: UNU-WIDER

Knox J, Hess T, Daccache A, Wheeler T (2012) Climate change impacts on crop productivity in Africa and South Asia. Environ Res Lett 7:1-8

Neumann JE, Emanuel KA, Ravela S, Ludwig LC, Verly C (2013) Assessing the risk of cyclone-induced storm surge and sea level rise in Mozambique. Working paper 2013/036. Helsinki: UNU-WIDER

Noy, I (2009) The macroeconomic consequences of natural disasters. J Dev Econ 88:221–231

OECD/DAC (2012). Electronic data downloaded in August 2012

Paltsev S (2012) Implications of alternative mitigation policies on world prices for fossil fuels and agricultural products. Working paper 2012/65. Helsinki: UNU-WIDER

Rosenfeld, D (2012) The coal mining sector in Mozambique: a simple model for prediction of government revenue. Paper presented at the Institute for Social and Economic Studies conference. September. Maputo

Schlosser CA, Strzepek K (2013) Regional climate change of the greater Zambezi River Basin: a hybrid assessment. Working paper 2013/040. Helsinki: UNU-WIDER

Schlosser CA, Gao X, Strzepek K, Sokolov A, Forest C, Awadalla S, Farmer W (2011) Quantifying the likelihood of regional climate change: a hybridized approach. Report 205. Joint Program on the Science and Policy of Global Change, Massachusetts Institute of Technology

Tarp F, Arndt C, Jensen HT, Robinson SR, Heltberg R (2002) Facing the development challenge in Mozambique: a general equilibrium perspective. Research Report 126. International Food Policy Research Institute, Washington, DC

Tol RSJ (2009) The economic effects of climate change. J Econ Perspect 23(2):29–51