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Adaptation to climate change in sub Saharan Africa

A multi-sector impact analysis for Burkina Faso

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Abstract

Several decades of successive droughts and desertification, caused by climatic changes, have made the Sahel region one of the must vulnerable to further climate change. This vulnerability is steadily increasing in scope and visibility and it leads to destroyed farmland, major food shortages, decimated herds, and considerable material and human losses. Adaptation to climate change is the adjustment in ecological, social or economic systems in order to alleviate adverse impacts of change or take advantage of new opportunities. However, well-intentioned adaptations can generate costs when wider issues or longer timeframes are considered. This paper develops a system dynamics model for the case of Burkina Faso. The model serves as a multi-sector impact assessment tool and estimates the vulnerability of different policy sectors to climatic changes. It also quantifies the synergies and trade-offs between different adaptation options. Model simulations show that the most cost-effective combination of adaptation options to compensate for the social and economic losses caused by climate change costs approximately 15% of those losses. The model contributes to building adaptive capacity in Burkina Faso by building awareness of the impacts of climate change, the necessity for a multi-sector adaptation strategy and by exploiting ways for maintaining economic growth.

Introduction

Climate change will bring about gradual changes such shifts of climatic zones due to increased temperatures and changes in precipitation patterns. Also, climate change is very likely to increase the frequency and magnitude of extreme weather events such as droughts, floods, and storms. While there is uncertainty in the projections with regard to the exact magnitude, rate, and regional patterns of climate change, its consequences will particularly impact developing countries. This is due to the economic importance of climate-sensitive sectors (e.g., agriculture) for these countries, and to their limited human, institutional, and financial capacity to anticipate and respond to the direct and indirect effects of climate change (IPCC, 2001). The macroeconomic costs of the impacts of climate change are highly uncertain, but very likely have the potential to threaten development in many countries (Thornton et al., 2006). Therefore, the task ahead is to increase the adaptive capacity of affected poor communities and countries.

Climate change policies either emphasize mitigation or adaptation. Mitigation refers to actions taken to permanently eliminate or reduce the long-term risk and hazards of climate change. Adaptation, on the other hand, refers to the ability of a system to adjust to climate change. For the world's poor, adaptation seems to be more important than mitigation for the next few decades (Campbell, 2009). Adaptation to climate change can be defined as an adjustment in ecological, social or economic systems in response to observed or expected changes in climatic stimuli and their effects and impacts in order to alleviate adverse impacts of change or take advantage of new opportunities (IPCC, 2001). Adaptations can generate short- and long-term benefits. However, they can also generate costs when wider issues or longer timeframes are considered (Adger, Arnell, & Tompkins, 2005).

The objective of this paper is to calculate the multi-sectoral impacts of climate change in Burkina Faso and to estimate the costs of adaptation. For this purpose, we develop a system dynamics model that captures the long-term social, economic and environmental development of Burkina Faso and that can be used as a scenario and impact analysis tool to inform the development of an integrated and long-term adaptation strategy.

Adaptation to climate change involves decisions from individuals, firms, civil society, as well as local, regional and national governments and international agencies. Actions associated with building adaptive capacity include communicating climate change information, building awareness of potential impacts, maintaining well-being and economic growth, or exploiting new opportunities (Adger, et al., 2005). The objectives of adaptation decisions most often focus on reducing the cumulative impacts of climate change, ensuring that adaptive measures taken by one actor do not adversely impact on others, and avoiding anticipated adverse impacts of climate change (Adger, et al., 2005). The integration of adaptation actions and policies across sectors remains a key challenge to achieve effective adaptation in practice (Adger, et al., 2005).

The model described in this paper addresses all these aspects of adaptation. It responds to the call that most environmental problems such as climate change require integration of many disciplines and methods of analysis. There also is a shift in interest and focus from global scales to regional and local scales. Models that help to integrate science findings with management and policy issues are needed. These models should include all the important linkages between the socio-ecological and economic sectors (Boko et al., 2007). The particular strength of the model described in this paper is the ability to investigate synergies and trade-offs between sectoral adaptation policies across policy sectors. Model simulations as well as the model itself in its function as impact assessment tool contribute to the three cornerstones of adaptation of reducing the sensitivity of the system to climate change; altering the exposure of the system to climate change; and increasing the resilience of the system to cope with changes (Adger, et al., 2005). The model allows testing the cross-sectoral impact of adaptation options that reduce the sensitivity of Burkina Faso's society, economy and environment by investments in infrastructure or agricultural management practices such as the use of soil and water management techniques. The model also shows how climate change mitigation activities in the energy sector alter the exposure of Burkina Faso to the effects of climate change. The model is, however, only marginally effective in increasing the resilience of Burkina Faso's society and ecology as the model in itself does not enable specific populations to recover from losses created by climate change.

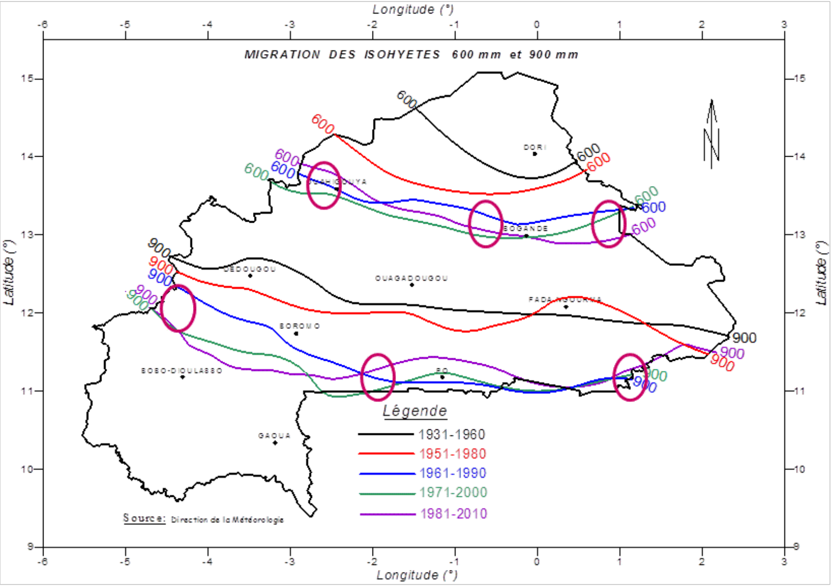
Burkina Faso

Burkina Faso is a landlocked country located in the middle of the West African Sahel region. With limited natural resources and a highly variable climate, Burkina Faso struggles to provide its dense population with food security and economic opportunity. Burkina Faso is dependent on agriculture, with roughly 80% of employment linked to subsistence farming. The country's soils tend to be poor in nutrients, have low water-holding capacity, and are largely degraded. When rainfall declines, dust storms occur, or temperature spikes, food supplies/yields are immediately affected. Located between the Sahara Desert to the north and coastal rainforests to the south, Burkina Faso is prone to chronic drought, floods, windstorms, and disease outbreaks. As a result of this fragility, Burkina Faso remains at the bottom of the UN's Human Development Index, ranking 162 out of 169 countries, with 46% of the population below the poverty line.

Measures to improve water retention and crop resilience to climate variation have started, but remain local and small scale. Low agricultural productivity continues to impede the nation's growth; therefore, major efforts to increase technical capacity, financial lending, water storage, crop diversification, and soil restoration are necessary. In addition, national weather early warning systems, environmental monitoring, and research on best practices will be essential to combat the impacts of climate change (Global Facility for Disaster Reduction and Recovery & Global Support Program of the Climate Investment Funds, 2011).

In Burkina Faso, there are three climatic zones: the Sahelian north with an average annual rainfall of less than 600 mm, the Sudano-Sahelian zone in the center with an average annual rainfall between 600 and 900 mm and the Sudanian zone in the south with an average annual rainfall that exceeds 900 mm, and a rainy season of about 6 months. Climate changes have led to a spatial shift in the extension of the three climatic zones (Figure 1). Over the past decades, the Sahelian zone in the north has expanded and the Sudanian zone in the south has diminished. This has led to an overall decline in the agricultural production potential, which is tightly linked to rainfall.

Figure 1: Shift in climatic zones between 1930 and 2010



Source: Direction de la Météorologie

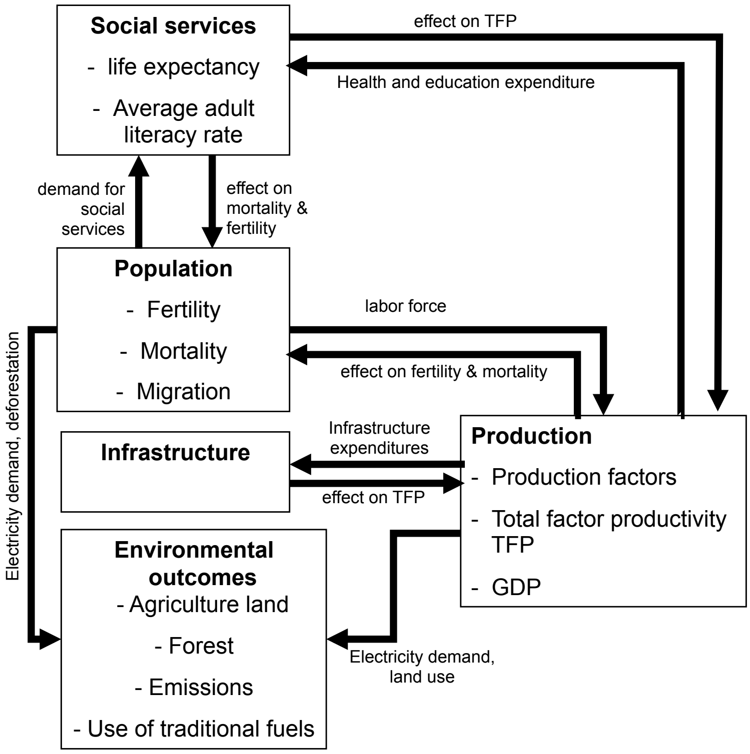
Approach

The model used in this paper is a simplified version of the Threshold 21-Burkina Faso (T21-BKF) model by Millennium Institute. Millennium Institute's modeling team developed the T21-BKF model in close collaboration with national actors in Burkina Faso and the United Nations Development Programme (Züllich, Kopainsky, & Pedercini, 2013). In the subsequent sections we describe the structure of the simplified model, how it integrates the impacts of climate change and adaptation options and the database used to calibrate the model. We then describe the scenarios and options designed for estimating the multi-sectoral impact of climate change and the costs of adaptation.

Model

Figure 2 shows the sub-system diagram of the simplified model that represents the main social, economic and environmental development processes and their interactions with each other. The model calculates these processes for the time horizon between 1990 and 2050.

Figure 2: Sub-system diagram

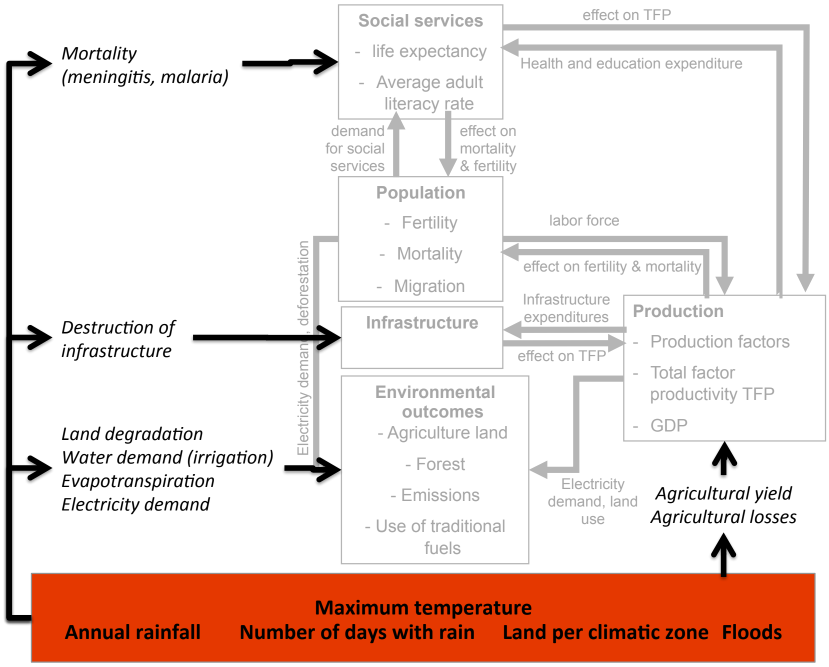


The most representative indicators of climate change in Burkina Faso for which data are available for the historical time period as well as for the future are:

- Annual average maximum temperature
- Annual rainfall
- Number of days with rain
- Land per climatic zone
- Intensity of floods

For these variables, we used the observed data for the past (1990-2010; national meteorological service) and projections for the future (2010-2050) from the University of Cape Town (http://cip.csag.uct.ac.za/webclient/webclient/login). The direct impact of these indicators travels through chains of causal relations through the entire social, economic and environmental system in Burkina Faso to create a series of indirect impacts. The impact of climate change indicators is visualized in Figure 3.

Figure 3: Inclusion of climate change impacts in the simulation model



Data

For the calibration of the model, a considerable amount of statistical data from national and international sources was used. There are data in two main categories:

- Time series data covering the historical time horizon of the model (1990 - 2010).
- Data quantifying the strength of a causal effect or unit costs of a policy. These data are used to estimate, for example, the impacts of different adaptation options.

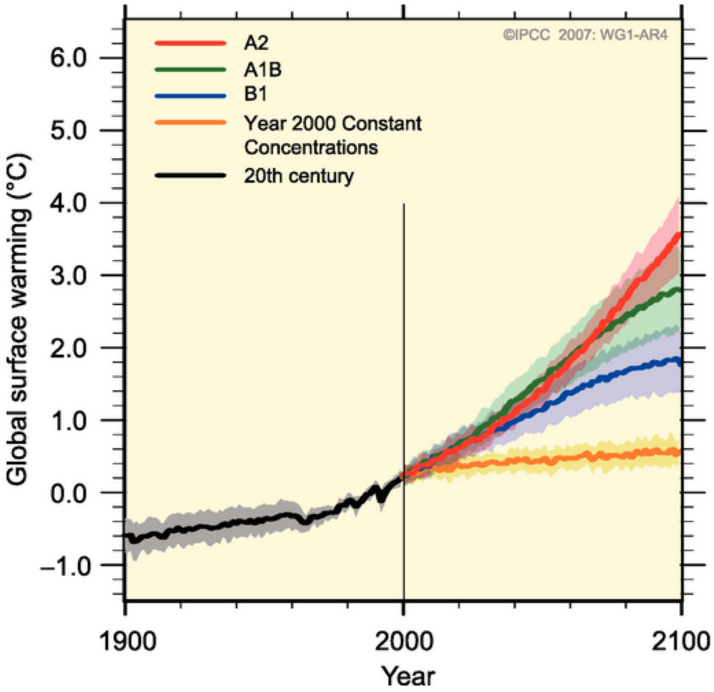
Scenarios

For the dynamic analysis of the impacts of climate change and the costs of adaptation, we defined three scenarios:

- A baseline scenario without climate change. This is a counterfactual scenario used to calculate the impact of climate change. This scenario assumes no further changes in the climate change indicators in the future, i.e., they are assumed to remain constant on today’s levels.
- Two climate change scenarios. Because there is considerable uncertainty regarding the direction and dimension of climate change, this study employed two main climate change scenarios: an intermediate scenario and worst case scenario.

The intermediate and worst case scenarios are based on two scenarios of the Intergovernmental Panel on Climate Change (IPCC, 2007a). IPCC scenarios include the latest information on emissions, economic restructuring in the world, the different rhythms and patterns of technological change and the range of different paths of possible economic developments. Figure 2 shows the projections of different scenarios of IPCC on global temperature.

Figure 4: IPCC global warming scenarios (IPCC, 2007b: 762)

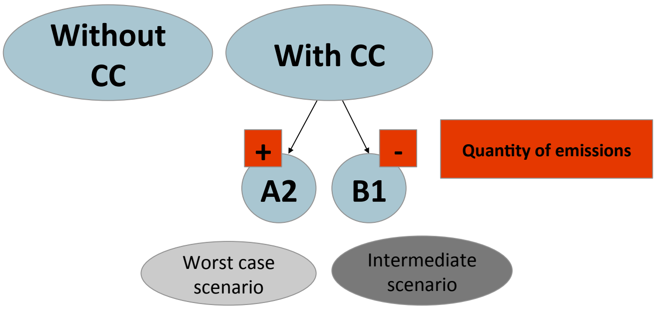


Notes: Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the scenarios A2, A1B and B1. Shading denotes the ±1 standard deviation range of individual model annual averages. The orange line is for the experiment where concentrations were held constant at year 2000 values.

Among the four families of scenarios developed by the IPCC, two extremes were selected for the analysis in Burkina Faso (see also Figure 5):

- The storyline and A2 family of scenarios is characterized by: a very heterogeneous world, self-reliance and preservation of local identities, the continuous growth of the world population, primarily regionally oriented economic development, per capita economic growth and technological change more fragmented and slower than in other storylines. In sum, this scenario assumes a continued increase in emission of greenhouse gases and serves as our worst case scenario.
- The storyline and B1 family of scenarios are characterized by: a convergent world, global population peaking in mid-century and then declining, a rapid change to a service and information economy, the introduction of clean technologies, efficient use of resources, global solutions to economic viability, social and environmental sustainability, including improved equity, and no additional initiatives to manage the climate. In sum, this scenario assumes a stabilization of emissions at the end of the 21st century and serves as our intermediate scenario.

Figure 5: Scenarios for model analysis



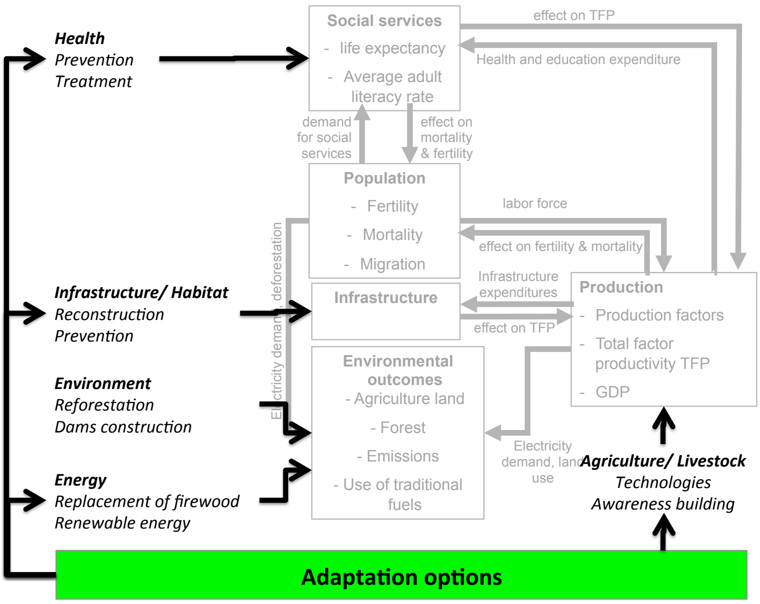
Adaptation options

The model allows testing adaptation options in several policy sectors such as agriculture, livestock, health, infrastructure, energy, and environment. Table 1 summarizes the adaptation options that are used to calculate the costs of adaptation. The last column in the table lists references that either describe examples of adaptations that are already observed in Africa or examples of adaptation options that have been tested in similar studies prioritizing adaptation needs. This column thus provides a justification of the selection of the specific adaptation options. Figure 6 visualizes the entry points of the adaptation options in the model.

Table 1: Summary of adaptation options

Policy sector	**Adaptation option**	**Justification**
Agriculture	The first category of adaptation options in agriculture relates to soil and water conservation techniques. These techniques are sustainable because they can increase performance without affecting the quality of the soil. Another technological option is the development and diffusion of improved crop varieties. The second category of adaptation options is that of strengthening agricultural services whose purpose is to facilitate the use and adoption of technological options.	Matondo, Peter, & Msibi, 2005; Orindi & Ochieng, 2005; Seck, Mamouda, & Wade, 2005
Livestock	Promotion of the transition from extensive to intensive livestock systems that enhance performance, but meet the capacity of the natural resource base.	Mortimore & Adams, 2001
Health	Preventive measures for meningitis and malaria. Treatment of meningitis and malaria cases.	Hay et al., 2002; Thomson 2006
Energy	Replacement of wood energy, i.e., promotion of alternatives in the fight against deforestation such as gas subsidies, energy efficiency (improved stoves), and solar cookers. Reducing energy demand through increased efficiency of air conditioning. Promotion of the generation of renewable energies such as hydro and photovoltaic energy.	Sanneh, Hu, Hsu, & Njie, 2013
Environment	Reforestation Dams	Abou-Hadid, 2006; Sanneh, Hu, Hsu, & Njie, 2013
Infra-structure	Reconstruction of damage caused by floods. Prevention - construction of gutters and awareness raising.	Chigwada, 2005; Sokona & Denton, 2001

Figure 6: Inclusion of climate change adaptation options in the simulation model



Results

Table 2 summarizes the most important economic, social, and environmental impacts of climate change. The values in the table indicate the difference in the year 2050 between the two scenarios with climate change and the baseline scenario without climate change.

Table 2: Summary of multi-sectoral impacts of climate change (percent by 2050 compared to the baseline scenario without climate change)

Indicator	**Intermediate scenario**	**Worst case scenario**
GDP	-5%	-12%
Agricultural production	-4%	-20%
Agricultural yield	-4%	-15%
Livestock production	-4%	-22%
Average adult literacy rate	-0.01%	-0.04%
Life expectancy	-0.6%	-1%
Greenhouse gas emissions	-2.5%	-6%
Electricity demand	---	-6%
Use of traditional fuels	+3%	+7%
Total renewable water resources	---	-40%

The impacts of climate change on agriculture and livestock are considerable and the losses in these two sectors amount to more than half of the total economic losses. The reduction of agricultural yields, overall agricultural production as well as livestock production is in line with results from other studies assessing the impact of climate change on agriculture in Africa (Boko, et al., 2007).

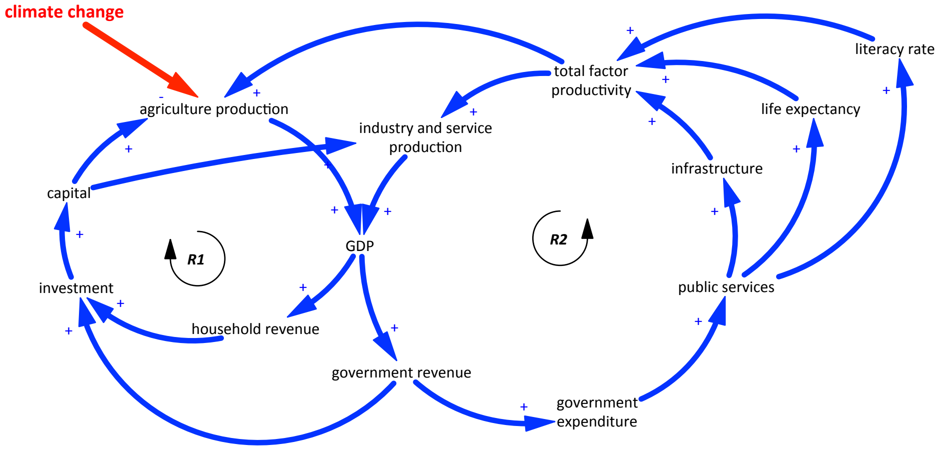
Electricity demand is fairly similar in the scenarios with and without climate change. In a scenario with climate change, the main driver of electricity demand is economic growth. In the intermediate scenario with climate change, electricity demand increases because of the increased use of air conditioning. Although electricity demand is fairly similar in the intermediate climate change scenario and in the scenario without climate change, greenhouse gas emissions differ between the two scenarios. Economic production, the main driver of electricity demand in the scenario without climate change, is mainly based on the use of fossil fuels while electricity for air conditioning can also be provided by other energy sources.

The use of traditional fuels is high and increasing in all scenarios. However, the scenario without climate change shows the lowest overall consumption of traditional fuels. In this scenario, GDP is higher, which increases government revenues and thus government expenditures. Some of these expenditures may be invested in promoting alternatives to traditional fuels such as gas. High consumption of traditional fuels is a considerable problem because it is one of the main drivers of the very high deforestation rates.

The impact of climate change on water resources is very direct. The decrease in precipitation in the worst case scenario associated with the increase in temperature causes a decrease in renewable water resources leading to increased water stress. This has serious consequences for the ecosystem and humans, such as the negative impact on crop yields discussed earlier.

The numbers listed in Table 2 highlight the impact of climate change on the economic, social and environmental development of Burkina Faso. To understand the magnitude of the impact it is important to emphasize that the direct effects of climate change, such as the impacts on agricultural production, offer only a partial explanation. In addition, the high degree of interconnection between variables in the system leads to the fact that direct effects affect reinforcing and balancing loops and thus generate impacts in all parts of the system. Thus, for example, climate change reduces agricultural production, which reduces overall gross domestic production (GDP) and consequently both the household and the government income. With the decline of income, investment and consumption are reduced and thus also further production potentials. Figure 7 shows some of the key reinforcing feedback loops that are responsible for the fact that the difference between a situation without climate change and with climate change increase over time.

Figure 7: Feedback loops causing a widening gap over time between a situation with climate change and one without climate change



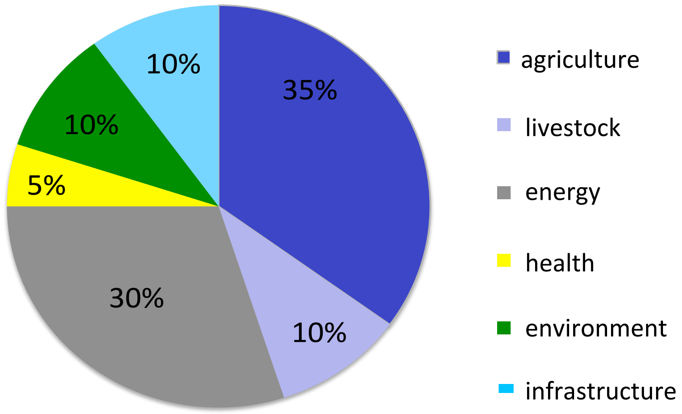
Notes: R1: private sector development; R2: public sector development

Costs of adaptation

In this section, we calculate the amount necessary to offset the impacts of climate change. Funding for adaptation is assumed to result from grants from outside the country. This assumption is in line with other studies (e.g., UNEP, 2011). The amount of investment necessary is calculated using optimization algorithms that minimize the difference between the GDP in the baseline scenario without climate change and GDP in the scenarios with climate change.

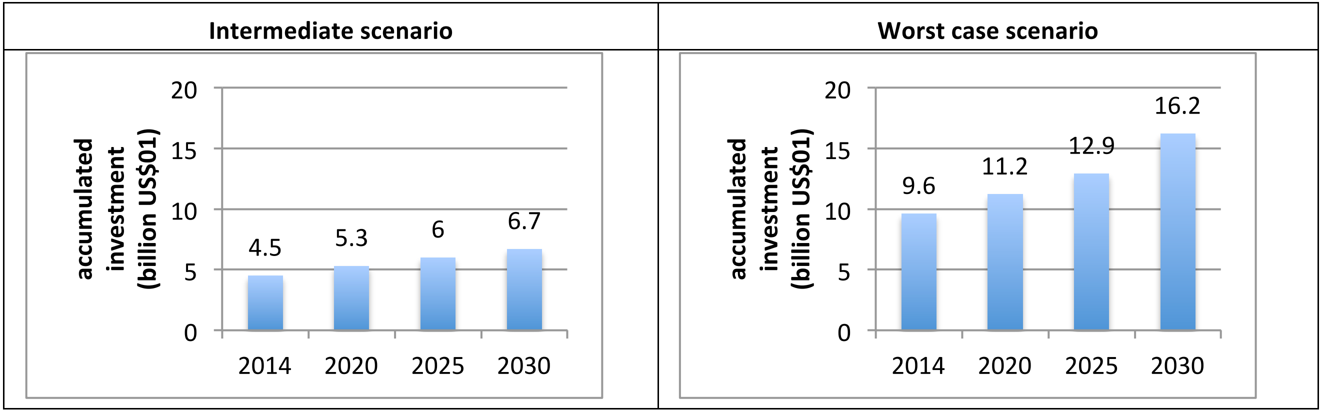
For the intermediate scenario the optimization simulations showed that 0.7% of GDP per year is needed to offset the negative impacts of climate change. In the worst case scenario, it is even 1.5% of GDP each year. The total accumulated investment costs to compensate for the impacts of climate change for the period between 2014 and 2050 is approximately 15% of the total accumulated losses in GDP that result from climate change (15% in both climate change scenarios). Overall investment needs to be allocated to the different policy sectors according to the following priorities: Agriculture; Energy; Livestock, Environment and Infrastructure; Health (see Figure 8).

Figure 8: Optimal allocation of adaptation investments to the different policy sectors



Adaptation costs are thus fairly moderate compared to their benefits, that is, in relation to the avoided economic losses. However, these costs increase significantly and in a non-linear way if the implementation of adaptation is delayed. Figure 9 compares the cost of adaptation for four different starting points, that is, for four different years in which the adaptation investments are first implemented (2014 which is the year used for all simulations so far, and 2020/2025/2030).

Figure 9: Adaptation costs as a function of the year in which adaptation investments are first implemented

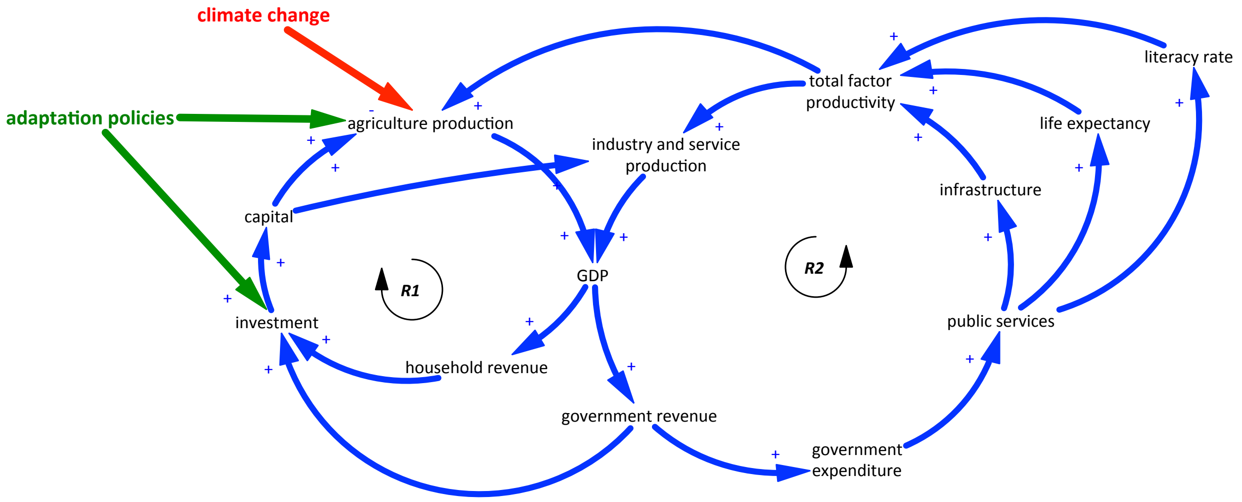

Intermediate scenario

Worst case scenario

Figure 9 shows that the accumulated costs (the sum of the investment that is necessary to compensate for the loss in GDP compared to the scenario without climate change) is about 20% larger if investment begins in 2020 instead of 2014 and approximately 35% greater with the beginning in 2025 and between 50% and 70% greater if first implemented in 2030.

These differences can be explained by several factors. On the one hand, a later onset of the additional investment means that in the preceding years, the negative impact of climate change already reduced economic power with the result that later, a larger difference must be compensated. On the other hand, the same loops are able to strengthen economic, social and environmental development if the investment starts earlier. They can thus develop more strength so that less investment is required later on (Figure 10).

Figure 10: Entry points of adaptation options



Conclusions

The objective of this paper was to calculate the multi-sectoral impacts of climate change in Burkina Faso and to estimate the costs of adaptation. For this purpose, we developed, validated and calibrated a system dynamics model that captures the long-term social, economic and environmental development of Burkina Faso. We used the model to compare three scenarios: A counterfactual scenario without further climate change, a scenario with moderate climate change and a worst-case scenario with climate change. The comparison between the scenario without climate change and the two scenarios with climate changes allowed calculating the multi-sectoral, economic, social and environmental impacts of climate change. The costs of adaptation were the amount of investment in the different policy sectors that is necessary to compensate for the impacts of climate change.

Regarding the impacts of climate change, our analysis showed that the impact is both serious and multi-sectoral. It is multi-sectoral because the direct effects of climate change or changes in rainfall, higher temperatures and natural disasters, have multiple effects that travel along causal chains across economic, social and environmental sectors. The impact of climate change is serious as climate change causes significant losses, that is, economic losses such as reductions in GDP, social losses caused by an increase in diseases and a reduction in the provision of health and education services, and environmental losses such as the reduction of forests or land degradation.

Model analyses have also shown that compensating for the effects of climate change requires additional investments in the order of 0.6% to 1.5% of Burkina's annual GDP. The accumulated costs of such investment are approximately 15% of the accumulated loss in GDP that climate change would cause without adaptation. These costs increase in a non-linear way if the implementation of adaptation is delayed. Although the costs of adaptation are considerable, they nevertheless allow benefits (avoided losses) that are much more considerable ().

Table 3: Costs and benefits of adaptation

Indicator	Without cc	Intermediate scenario	Worst case scenario
GDP in 2050	36.8	35.1 billion US$01	32.5 billion US$01
Losses in GDP (2014-2050)	-	28 billion US$01 **Benefits of adaptation**	55 billion US$01
Adaptation costs (2014-2050)	-	4.5 billion US$01 **Costs of adaptation**	9.6 billion US$01

All our results show that an effective adaptation strategy must result from multi-sectoral collaboration because it is not only the impacts of climate change that go through causal chains across different policy sectors but also the impacts of adaptation options. Only multi-sectoral collaboration enables integrated and coherent management of climate change. Multi-sectoral collaboration will also allow for the development of an adaptation strategy that is consistent with sectoral policies and development strategies in the medium and long term. This emphasizes the need for dealing with adaptation to climate change not as a standalone issue but in the context of integrated development planning and poverty reduction strategies.

Acknowledgements

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