Report on Initial Vulnerability Assessment for Each Case Study

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SEVENTH FRAMEWORK PROGRAMME

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CONTENTS

1 Introduction

Vulnerability and its causes play an essential role in determining impacts. Understanding vulnerability is therefore as important as understanding the future pressures such as climate and global change itself. The IPCC (McCarthy et al., 2001) defines vulnerability as 'the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity'. In order to adapt this definition to the requirements of the WETwin project, we substitute the term 'climate' by 'external and internal drivers'. Since, the assessment of vulnerability of WETwin case study areas is not only subject to climate change but global change in general, including also socio-economical aspects.

A qualitative assessment of the most relevant future drivers and pressures will be developed for each case study area. This includes a qualitative assessment of the internal pressures like changes in demography, economic development, regional water demands, and land use. Furthermore, the qualitative assessment includes external pressures, such as climate change and changes derived from global scenarios following socio-economic pathways, as defined by the Intergovernmental Panel on Climate Change (IPCC). For this purpose three global scenarios were developed which are in line with the IPCC SRES scenarios (Nakicenovic & Swart, 2000) but complemented with recent trends and ideas derived from Millennium Assessment Scenarios (Cork et al., 2005).

A set of projections into the future (scenarios) is defined for the most important drivers in the form of storylines applicable for the sites regions. The scenarios are then interpreted for the different sites. Since every projection into the future is associated with uncertainty, different scenarios have to be formulated to reproduce the range of possible changes and therefore to quantify the uncertainty. The final step is to quantify the different types of adaptive capacity in consultation with the local experts.

Vulnerability assessment for the WETwin case study areas is a process including the following steps:

1. Development of global change scenarios (Chapter 2)
2. Development of DPSIR chains for each case study (Chapter 3)
3. Definition of site-specific storylines (Chapter 4)
4. Initial vulnerability/impact assessment for the southern case studies (Chapter 5)

The development of global change scenarios is important to determine boundary conditions for regional scenarios. The primary objective of the development of DPSIR chains (Driving force, Pressure, State, Impact, Response) is to identify and explore the major environmental and livelihood problems (impacts) at the study sites. Site-specific storylines are important to focus on specific research questions. According to Füssel (2007), it is fundamental to include four dimensions into the storylines in order to describe a vulnerable situation. Finally, these storylines support the development of regional scenarios. Indicators are necessary to quantify and/or qualify changes of the system state and are a fundamental basis for the vulnerability assessment.

2 Global Scenarios

2.1 Introduction

Scenarios are a central component in assessment processes for a range of global issues, including climate change, biodiversity, agriculture, and energy (O'Neill et al., 2008). Global change scenarios play an essential role in vulnerability assessment of the WETwin case studies. They determine boundary conditions for scenario downscaling to the regional scale, and, together with site specific storylines, they form the basis for the development of regional socio-economic scenarios.

Three global change scenarios are outlined here that are designed to assist the development of regional scenarios – in collaboration with case study leaders and local experts. They describe possible future developments of the world and are basically in line with the IPCC-SRES scenarios (Nakicenovic & Swart, 2000). The scenarios were complemented with ideas and assumptions developed in the frame of the Millennium Assessment (MA) scenarios (Carpenter et al., 2005) which in turn use the IPCC-SRES scenarios as a basis for their assumptions about the energy and climate developments (Nelson, 2005). Furthermore, the three global change scenarios were supplemented with "new" future demographic trends and economic growth at the country level with respect to new insights (IIASA, 2007; Van Vuuren et al., 2007). The purpose of the illustration of these global storylines is to support and stimulate visions of how case study regions might develop in a changing world. For instance, liberalized world markets could lead to an increase of the production of agricultural goods in a certain region. In contrast to this, in a world with a focus on regional solutions and self-reliance, agricultural production of the same region might decrease, or the selection of produced goods is controlled by regional demands rather than oriented at world market prices.

As the IPCC-SRES scenarios, the introduced global change scenarios are divided into globalization (G) or regionalization (R) and with focus on economy (Ec) or environment (Env). Following scenarios are outlined:

- G-Ec: globalization with focus on economy
- G-Env: globalization with focus on environment
- R-Ec: regionalization with focus on economy

Why using a terminology different from IPCC-SRES?

The assumptions formulated for each scenario are generally in line with the IPCC-SRES scenario storylines. Some trends underlying the SRES scenarios are not up to date and where modified after suggestions by (Arnell et al., 2004; van Vuuren et al., 2007). For instance: "the SRES land cover trends are consistent with the narrative storylines, they are inconsistent with recent trends. Under none of the storylines is there a sustained continued deforestation, for example, and crop areas decrease under all of them" (Arnell et al., 2004). Also there exist discontinuities in the IPCC-SRES scenarios regarding GDP growth rates. This mainly holds for Central America and Africa (van Vuuren et al., 2007).

Furthermore, the developed scenarios are complemented with stories from MA scenarios. Thus, ideas from different sources are mixed (without compromising the consistency of the scenarios). Consequently, new names were invented in order to avoid confusion.

2.2 Scenarios

Scenario development is a way to explore possibilities for the future that cannot be predicted by extrapolation of past and current trends (Cork et al., 2005). The comparison of different scenarios supports the understanding of potential impacts of today's decisions on tomorrow's ecosystems and human well-being (Carpenter et al., 2005). Scenarios offer a means for examining the forces shaping the world and the uncertainties that lie ahead (Ayeni et al., 2002). Some key issues to consider in the formulation of scenarios include: the boundary; the current state; the definition and determination of driving forces; the narrative, or storyline; and images of the future (Ayeni et al., 2002, Chapter 4). Ayeni et al. (2002) name three arguments why long-range future cannot be extrapolated: ignorance, surprise and volition.

- Insufficient information on both the current state of the system and on the forces governing its dynamics leads to a classical statistical dispersion over possible future scenarios.
- Even if precise information were available, complex systems are known to exhibit turbulent behaviour, extreme sensitivity to initial conditions and branching behaviours at various thresholds. Therefore, the possibilities for novelty, surprise and emergent phenomena make prediction impossible.
- The future is unknowable because it is subject to human choices that have not yet been made.

A note for the excited reader: *An interesting article about global scenario development was published by Raskin (2008). The author proposes three scenarios (Conventional Worlds, Barbarization, Great Transitions) each with two variations.*

2.2.1 G-Ec Scenario

The underlying assumptions for this scenario are generally in line with the IPCC-SRES scenario A1B. According to the A1 storyline and scenario family it describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Baer (2009) describes the A1 storyline as representing the desired future of 'neoliberals' who prioritize market-driven economic growth. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income (IPCC, 2000). Just as the A1B scenario, the G-Ec scenario is not relying too heavily on one particular energy source (fossil intensive or non-fossil energy sources). Similar improvement rates applied to all energy supply and end use technologies is assumed. In addition to these assumptions some ideas from the "Global Orchestration" scenario (Cork et al., 2005) are included in the G-Ec scenario in order to present a more illustrative and more complete picture of this scenario.

Global liberalized markets are well developed and the society is worldwide connected. Hence, the focus is more on individuals rather than on states. Market regulations are only implemented where appropriate. Global cooperation improves social and economic well-being of all people and protects and enhances global public goods and services (such as public education, health, and infrastructure). The existence of supra-national institutions is usually an optimal precondition to deal with global environmental problems. But problems that have little apparent or direct impact on human well-being are given a low priority in favor of policies that directly improve well-being. Furthermore the approach to deal with environmental problems is reactive, hence, problems threatening human well-being are dealt with only after they become apparent. Humans strongly belief in the ability to find technological approaches to repair or replace lost ecosystem functions, (just as it always has in the past) and ecosystems are considered to be robust to the impacts of humans. The society runs the risk of underestimating environmental threats and is not well prepared for ecological surprises.

Increasing connections among people and nations at social, economic, and environmental scales hold benefits (such as economic prosperity, increasing equality, wealth, and global coordination) and risks (focus on global problems insufficient to sustain local and regional ecosystem services, breakdowns of ecosystem services create inequality, reactive management more costly than preventive or proactive approaches) at the same time (Cork et al., 2005).

Although there is a strong trend to social and economical convergence among regions, disparities will not completely disappear in the next decades. Hence, differences between poor and wealthy regions will remain with the consequences that poorer regions will still be more vulnerable to ecological and economical crisis.

2.2.2 G-Env Scenario

The underlying assumptions of the G-Env scenario are generally in line with the IPCC-SRES scenario B1. The B1 storyline and scenario family describes a convergent world with the same global population (as A1B or G-Ec, respectively) that peaks in mid- century and declines thereafter. Economic structures are oriented toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives (IPCC, 2000). According to Baer (2009) the B1 scenario represents the desired future of globally oriented 'greens' who prefer deliberate efforts to achieve sustainability and greater equality. Additional ideas and assumption for the G-Env scenario are based on the “TechnoGarden” scenario (Cork et al., 2005).

The G-Env scenario is characterized by a connected world that strongly relies on technology and on highly managed and often-engineered ecosystems. Eco-efficiency is well developing. Solutions to environmental problems are usually technology-based. The strong feel for international cooperation is beneficial for reforms and policy initiatives resulting in good conditions to tackle global environmental problems. Environmental taxation and development of property rights to ecosystem services are important instruments to reduce pollution on the one hand and to support sustainable management and preservation of ecosystem functions on the other hand. Property rights are assigned to a diversity of individuals, corporations, communal groups, and states that act to optimize the value of their property. It is assumed that ecological management and engineering can be successful, although it does produce some ecological surprises that affect many people (Cork et al., 2005).

Similar to the G-Ec scenario there is an over-reliance on highly engineered systems and an overestimation on human technological capabilities to solve any environmental problem just in time. In contrast to the G-Ec scenario, environmental problems are often identified before they become severe.

What conditions at the beginning of the 21st century lead to the development of such a storyline? Poverty, inequality, and unfair global markets, together with environmental degradation, were pressing problems on the agendas of global and national decision-makers. “A key activity in which these issues intersected was agriculture. Agriculture was, and remains, the most extensive human modification on Earth's surface. World markets for agriculture were unequal. Trade barriers and perverse subsidies encouraged pollution in the rich world, impoverished rural communities, and undercut development in poor countries. A broad coalition of new-liberals, development advocates, and environmentalists organized against agribusiness to stimulate a global transformation of agriculture” (Cork, et al., 2005). New EU policies encouraged farmers to manage their land to produce a bundle of ecosystem services rather than focusing on crop production alone. People were paid for improving water quality by preserving key watersheds. Farmers realized that they could increase their income by receiving money to provide additional services. This increased the expansion of multifunctional landscapes. Agriculture changed rapidly towards a balancing between food production and ecosystem services. Export subsidies and trade barriers were removed from global agricultural trade. The liberalization of agricultural markets leads to a huge growth in food imports into richer countries. Increasing investments from agribusiness in agriculture in Eastern Europe, Latin America, and Africa result in agricultural intensification. New varieties of existing crops were bred and locally adapted genetically modified crops and farming systems created. Profitability and farm production increases in Asia, Africa, and Latin America (Cork et al., 2005).

The G-Env scenario operates somewhat similarly to the G-Ec scenario, with substantial improvements in crop yields combined with a lower preference for meaty diets reducing pressure on crop area expansion. Increased food demand is also met through exchange of goods and technologies. Both calorie consumption levels and the reduction in the number of malnourished children are similar, albeit somewhat lower than in the G-Ec scenario.

Potential benefits of the G-Env scenario are: Win-win solutions to conflicts between economy and environment, optimization of ecosystem services, and societies that work with rather than against nature.

Potential risks are: Technological failures have far-reaching effects with big impacts, wilderness eliminated as “gardening” of nature increases, and people have little experience of non-human nature which leads to simple views of nature (Cork, et al., 2005).

2.2.3 R-Ec Scenario

The basic assumptions for this scenario are generally in line with the IPCC-SRES scenario A2. The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities with less emphasis on economic, social, and cultural interactions between regions. Fertility patterns across regions converge very slowly, which results in continuously increasing global population (IPCC, 2000). In this storyline there is less emphasize on economic interactions between regions – compared to the other scenarios. Hence, economic development is uneven and primarily regionally oriented. Global average per capita income and per capita economic growth is more fragmented and slower than in other storylines. The income gap between industrialized and developing parts of the world does not narrow. Social and political structures diversify where some regions move toward stronger welfare systems and reduced income inequality, while others move toward “leaner” government and more heterogeneous income distributions (Nakicenovic and Swart, 2000). Due to the relatively low mobility of people, ideas, and capital technology diffuses rather slowly and technological change is heterogeneous. Although attention is given to potential local and regional environmental change, it is not uniform across regions and global environmental concerns are relatively weak.

Some ideas from the “Order from Strength” and “Adapting Mosaic” scenarios (Cork et al., 2005) are used to supplement the R-Ec storyline. Due to the low emphasis on international cooperation and social and cultural interactions, the regionalized and fragmented world is concerned with security and protection, emphasizing primarily regional markets, and paying little attention to the common goods. National environmental policies focus on securing natural resources seen as critical for human well-being. The environment issues are seen as secondary to other challenges. Just as in the G-Ec scenario, people strongly belief in the ability of humans to solve environmental challenges with technological measures. The approach to ecosystem management is generally reactive. But there is great regional variation in management techniques. Some local areas explore adaptive management, using experimentation, while others manage with command and control or focus on economic measures.

2.2.4 Benefits and Risks of Globalization, Regionalization, and Technological Progress

The arguments listed in the following tables do not claim to be complete. They were derived from the section additional insights emerging from scenarios (Cork et al., 2005).

Table 2.1. *Some Benefits and Risks of Globalization*

Benefit	Risk
Increasing global cooperation and a focus on global public good is likely to improve overall human well-being.	Ecological crises can accentuate inequalities as they tend to affect poor regions and countries more than wealthy regions.
A global development that emphasizes environmental technology and engineered ecosystems will contribute to sustainable development by allowing for greater efficiency and optimal control of ecosystems.	Global development of environmental technology and engineered ecosystems may lead to losses in local, rural, and indigenous knowledge and cultural values.
	Globally controlled institutions can be too large and rigid to respond effectively to ecological surprises, yet local institutions may neglect important linkages for anticipating and managing such surprises.

Table 2.2. *Some Benefits and Risks of Regionalization*

Benefit	Risk
Local problems become more tractable, and can be addressed by citizens.	Emphasis on adaptive management and learning at local scales may be achieved at the cost of overlooking global problems that may result in global environmental surprises with serious local repercussions.
Protection of key natural resources in richer regions could see an improvement.	Attention to global problems such as climate change and marine fisheries may decrease, leading to increasing magnitude of their impacts.
	Strategies that focus on local and regional safety and protection may disregard cross-border and global issues, restrict trade and movement of people, and increase inequalities.
Regionalization might offer security in the face of aggression, environmental pests, and diseases.	Regionalization increases risks of longer-term internal and international conflict, ecosystem degradation, and declining human wellbeing.
Local management of ecosystems provides better opportunities for more effective and fairer	A globally compartmentalized, environmentally reactive world could mask developing ecological

access to ecosystem services on local scales, but local strategies are more likely to be effective when accompanied by measures to ensure regional and global coordination.	and social disasters for several decades.

Table 2.3. *Some Benefits and Risks of Technological Progress*

Benefit	**Risk**
Technological progress can improve and support sustainable management of the environment.	Increasing confidence in human ability to manage, tame, and improve nature may lead people to overlook factors that sometimes cause breakdowns of ecosystem services.
Green technology reduces emissions of greenhouse gases.	Large scale technological solutions carry the internal risks of failure and can engender technology-related ecological surprises.
Genetically modified crops and farming systems can increase agricultural productivity and contribute to food security.	Public acceptance of genetically modified crops is relatively low.

2.2.5 Comparison of the Three Global Scenarios

Table 2.4. *Scenario Comparison (derived from IPCC (2000); Arnell et al. (2004); Cork et al. (2005))*

	G-Ec (A1B) (global/economic)	**R-Ec (A2) (regional/economic)**	**G-Env (B1) (global/environment.)**
Population growth (see Figure 2.5)	Low	High	Low
Economic growth (see Figure 2.6)	Very high	Medium (diverse) Low in developing countries; medium in industrialized countries	High
GDP growth per capita and year (Figure 2.7)	Ind.: US$ 817 Dev.: US$ 533	Ind.: US$ 332 Dev.: US$ 118	Ind.: US$ 514 Dev.: US$ 371
Service and information economy	High/medium		Very high
Introduction of new technologies	Rapid	Slow (diverse)	Medium
Resource efficiency (see Figure 2.8 and Figure 2.9)	Medium/low	(diverse)	High/medium

Resource availability	High/medium	Low	Low
Energy use	Very high/high	High	Low
Land use changes	Low-medium	Medium-high	High
(see Figure 2.2 and Figure 2.4)	Cropland +3% Forest -2%		Cropland -28% Forest +30%
Global sustainability solutions to:			
• Economy	High/medium	Low	High
• Society	High/medium	Low	High
• Environment	High/medium	Low	High

Table 2.5. *Economic Characteristics of the Three Scenarios (derived from Nakicenovic & Swart (2000); Cork et al., (2005))*

G-Ec (A1B)	**R-Ec (A2)**	**G-Env (B1)**
A1 world invests its gains from increased productivity and know-how primarily in further economic growth (high rates of investment and innovation in technology → rapid and successful economic development → rapid introduction of new and more efficient technologies	The A2 world "consolidates" into a series of economic regions (differentiated world) → economic growth is uneven → slower technological change (compared to A1) → technological change is heterogeneous (more rapid than average in some regions and slower in others)	Fast-changing and convergent world → economic development is balanced → relatively smooth transition to alternative energy systems
Communication technology, advances in transport, and intensive mobility plays a central role → economic convergence results from these advances → relatively high level of convergence in the per capita income levels	People, ideas, and capital are less mobile so that technology diffuses more slowly → low trade flows, relatively slow capital stock turnover (compared to A1)	Incentive systems, combined with advances in international institutions → rapid diffusion of cleaner technology → relatively high level of convergence in the per capita income levels
Strong commitment to market-based solutions	Self-reliance in terms of resources → Regions with abundant energy and mineral resources evolve more resource-intensive economies, while those poor	High levels of economic activity → a higher proportion of this income is spent on services rather than on material goods, and on quality rather than quantity, because the emphasis on material goods

	in resources place a very high priority on minimizing import dependence Less emphasis on economic interactions between regions	is less → resource prices are increased by environmental taxation → Massive income redistribution and presumably high taxation levels may adversely affect the economic efficiency and functioning of world markets

Table 2.6. *Socio-Economic Characteristics of the Three Scenarios (derived from Nakicenovic & Swart (2000); Cork et al., (2005))*

G-Ec (A1B)	R-Ec (A2)	G-Env (B1)
Demographic and economic trends are closely linked, as affluence is correlated with long life and small families (low mortality and low fertility)	Fertility rates decline relatively slowly	Demographic transition to low mortality and fertility (same rate as in A1, but for different reasons) it is motivated partly by social and environmental concerns
Regional average income per capita converge and distinctions between "poor" and "rich" countries eventually dissolve	Income gap between now-industrialized and developing parts of the world does not narrow, (unlike in the A1 and B1)	High levels of economic activity and significant and deliberate progress toward international and national income equality (global income one-third lower than in A1). Efforts to achieve equitable income distribution are effective. Strong welfare net prevents social exclusion on the basis of poverty.
High rates of investment and innovation in education / High savings and commitment to education at the household level	Social and political structures diversify; some regions move toward stronger welfare systems and reduced income inequality, while others move toward "leaner" government and more heterogeneous income distributions	Investments in equity and social institutions

This world is not necessarily devoid of problems … problems of social exclusion, increased pressure on the global commons...	People, ideas, and capital are less mobile and there is less emphasize on social and cultural interactions between regions	Governments, businesses, the media, and the public pay increased attention to the environmental and social aspects of development

Table 2.7. *Environmental Characteristics of the Three Scenarios (derived from Nakicenovic & Swart (2000); Cork et al., (2005))*

G-Ec (A1B)	R-Ec (A2)	G-Env (B1)
Energy and mineral resources are abundant in this scenario family because of rapid technical progress, which both reduces the resources needed to produce a given level of output and increases the economically recoverable reserves.	Regions with abundant energy and mineral resources evolve more resource-intensive economies, while those poor in resources place a very high priority on minimizing import dependence	The B1 world invests a large part of its gains in improved efficiency of resource use ("dematerialization"), and environmental protection (A1 world invests its gains from increased productivity and know-how primarily in further economic growth)
Rapid technological progress "frees" natural resources currently devoted to provision of human needs for other purposes	Self-reliance in terms of resources. High-income but resource-poor regions shift toward advanced post-fossil technologies (renewables or nuclear), while low-income resource-rich regions generally rely on older fossil technologies.	Technological change and increased resource efficiency plays an important role. Reduced material wastage by maximizing reuse and recycling, reductions in pollution
Energy intensity decreases at an average annual rate of 1.3%	Final energy intensities decline with a pace of 0.5 to 0.7% per year.	Extensive use of conventional and unconventional gas as the cleanest fossil resource during the transition, but the major push is toward post-fossil technologies. relatively smooth transition to alternative energy systems. Relatively low GHG emissions.
The concept of environmental quality changes in this storyline from the current emphasis on "conservation" of nature to active "management" of natural and environmental services, which increases ecologic resilience	Global environmental concerns are relatively weak, although attempts are made to bring regional and local pollution under control and to maintain environmental amenities	Incentive systems, combined with advances in international institutions, permit the rapid diffusion of cleaner technology

G-Ec (A1B)	R-Ec (A2)	G-Env (B1)
Environmental amenities are valued	Although attention is given to potential local and regional environmental damage, it is not uniform across regions	High level of environmental and social consciousness and institutional effectiveness combined with a globally coherent approach to a more sustainable development including environmental and social aspects
	With substantial food requirements, agricultural productivity is one of the main focus areas for innovation and research, development, and deployment (RD&D) efforts, and environmental concerns	Land use is managed carefully. Strong incentives for low-input, low-impact agriculture, along with maintenance of large areas of wilderness, contribute to high food prices with much lower levels of meat consumption than those in A1

2.3 Socio-Economic Projections

This chapter summarizes and illustrates existing projections of population development, GDP development, energy consumption, and land use change underlying the global change scenarios. Projected data are available at two different spatial scales, at the IPCC-SRES world region scale and/or at the country scale. Data on land use change and energy consumption are only available for IPCC-SRES world regions. Population and GDP development data are available for both the SRES regions and at the country level. Climate data projection is discussed in section 2.4.

2.3.1 SRES regions

The IPCC emissions scenarios include projections of various parameters at the scale of SRES regions (see Table 2.8 and Figure 2.1) and are based on the results of six integrated assessment models: AIM, ASF, IMAGE, MESSAGE, MINICAM, MARIA. A brief description of these models is given in Nakicenovic & Swart (2000).

Table 2.8. *SRES Regions (Nakicenovic & Swart, 2000)*

SRES Region	Description
World	World
OECD90	The OECD90 region groups together all countries that belong to the OECD as of 1990, the base year of the participating models, and corresponds to Annex II countries under UNFCCC (1992).
REF	The REF region comprises those countries undergoing economic reform and groups together the East European countries and the Newly Independent States of the former Soviet Union. It includes Annex I countries outside Annex II as

	defined in UNFCCC (1992).
ASIA	The ASIA region stands for all developing (non-Annex I) countries in Asia.
ALM	The ALM region stands for rest of the world and includes all developing (non-Annex I) countries in Africa, Latin America and the Middle East.

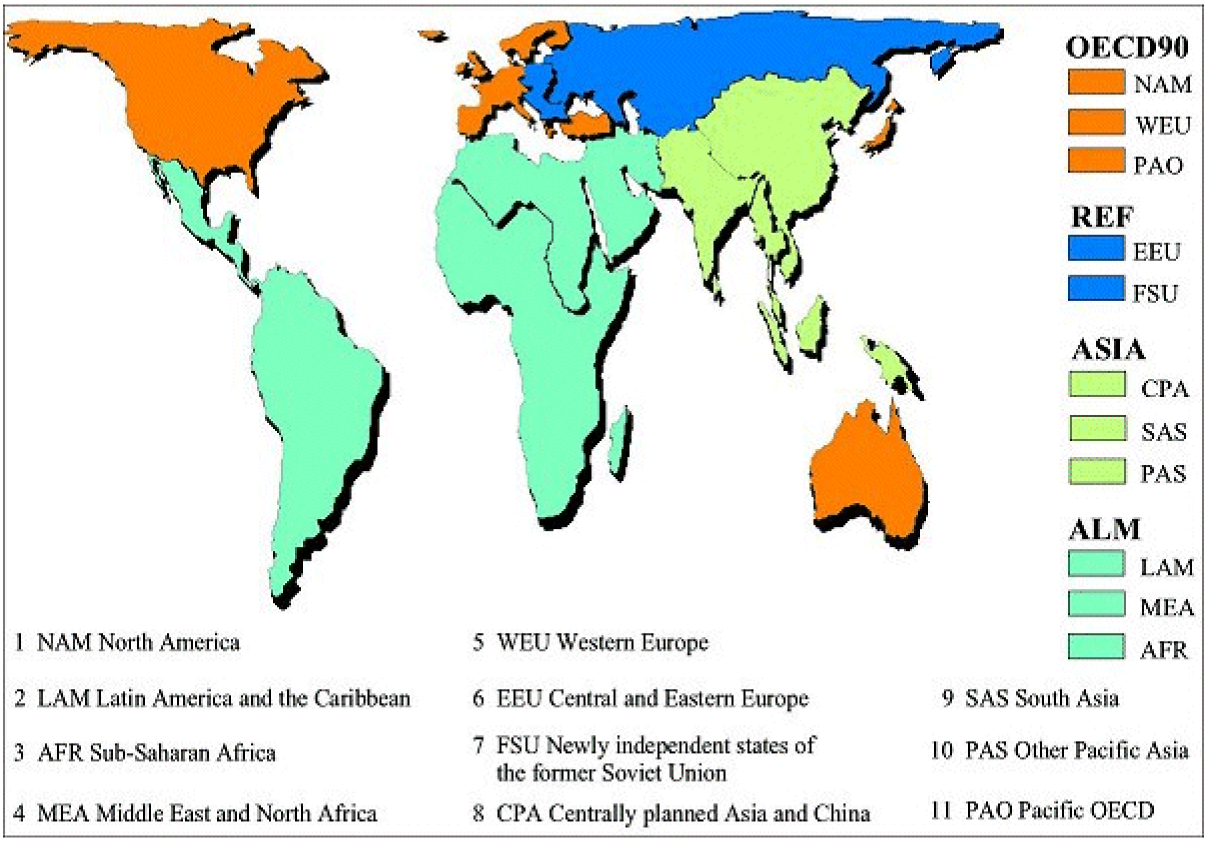


Figure 2.1. *SRES regions, http://www.ipcc.ch/ipccreports/sres/emission/index.php?idp=90*

According to the differentiation of SRES regions (Table 2.8 and Figure 2.1), the four southern WETwin case studies belong to the ALM region.

2.3.1.1 Land Use

According to Arnell et al. (2004) there are three issues in the application of the SRES world-region projections to estimate future land cover:

- Observed area of cropland summed across each region is greater than the baseline value used in the SRES projections.
- Everywhere within a major world region land use changes at the same rate. In practice, land cover change is likely to be greatest where population and population growth rates are greatest.

- There is a mismatch between recent trends and projected future cropland change in two of the SRES storylines (Levy et al., 2003).

According to Arnell et al. (2004) the SRES projections are very inconsistent with current trends and likely future patterns of land use change. The B1 scenario projects a decrease in cropland area and an increase in forest cover – which is consistent with the assumptions behind the scenarios but inconsistent with trends over the last century (Arnell et al., 2004). In some developing countries, especially in Africa, increase in input levels and intensification of production (of crop yields) are likely to continue for some time, but may also ultimately level off meaning that further increases in agricultural productivity will have to come through the expansion of land under cultivation. Demand for food, however, is allowed to vary between scenarios as it is linked to per capita GDP (Arnell et al., 2004) and population development. Deforestation of areas for permanent pasture rather than cropland may be a significant term, particularly in South America (Levy et al., 2004).

As reported by Levy et al., (2004) "there is large uncertainty in the future trend in cropland area as population increases. Until very recently, cropland area has shown a linear increase with population. However, in the last 50 years, in which the population has doubled, the increase in cropland area has been very small. How this trend will continue with a possible further doubling of the population over the next century is clearly highly uncertain".

The following charts are illustrating the underlying assumption for the SRES regions World, OECD90, and ALM and the three scenarios: A1B (G-Ec), A2 (R-Ec), and B1 (G-Env). The data sources are results from the six integrated assessment models, where five models produce land cover trends for the A1B and B1 SRES scenarios and only two models for the A2 scenario. The projections show oftentimes large differences. Hence, in order to assess a general trend of change one should basically consider the median value. Corresponding data are available at: http://sres.ciesin.org/final_data.html.

Figure 2.2 shows projections of cropland development underlying the three global change scenarios. The A1B (G-Ec) scenario shows no significant trends in all regions. In the A2 (R-Ec) scenario the cropland area is assumed to slightly increase in all regions. The B1 (G-Env) scenario shows a different pattern of change. There is a declining trend of cropland area projected for the OECD90 region and a rapid increase in the ALM region up to the year 2040. After 2040 cropland area in the ALM region is assumed to decrease until it reaches approximately the same extent as in 1990.

As shown in Figure 2.3 the integrated assessment models start in the year 1990 already with a broad range of assumptions concerning the area of forest cover for the OECD90 and ALM region. Whereas there is almost accordance of forest area of the world in 1990. Due to the broad range of projections the results are highly uncertain. The A1B (G-Ec) scenario shows a slight decreasing trend for the ALM region and a slight increase of forest area for the OECD90 region. In the A2 (R-Ec) scenario the trend in forest area decrease is more significant for the ALM region and shows an increasing trend for OECD90 countries. An increasing trend of forest cover for all regions is assumed by the B1 (G-Env) scenario.

An increase of agricultural area used to produce energy biomass is assumed by all assessment models for all regions and all scenarios. Figure 2.4 illustrates these projections. The increasing trend is most significantly in the A1B (G-Ec) scenario. Regarding the model median the projections assume a maximum area of ~550 million hectare for the entire world at the end of the 21st century in the A1B (G-Ec) scenario. In the A2 (R-Ec) scenario the maximum extent is ~400 ha and in the B1 (G-Env) scenario ~300 ha. Furthermore, the models assume a more significant trend of increasing agricultural area used for energy biomass in the ALM region than in the OECD90 region.

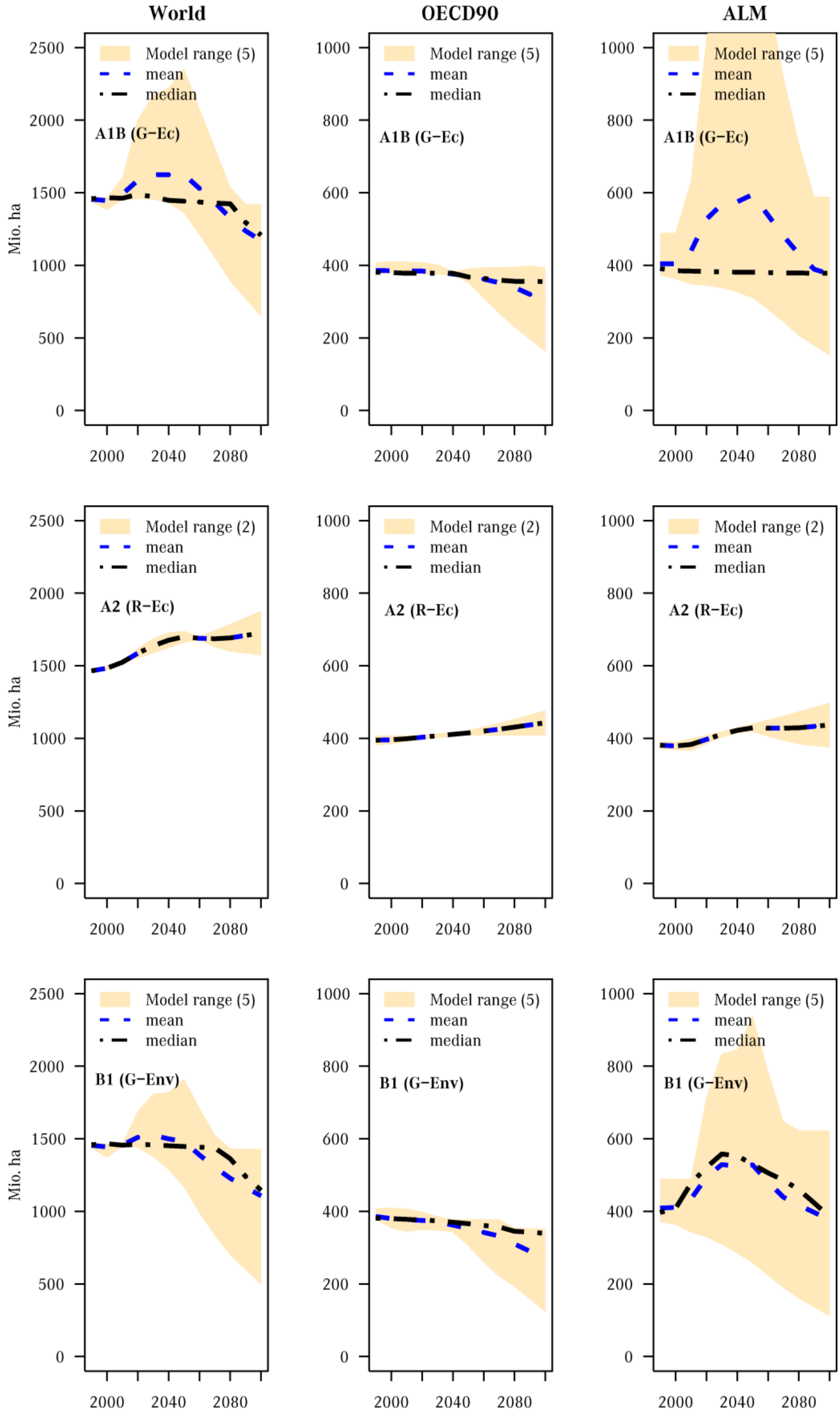


Figure 2.2. *Projections of Cropland Area. Data source:* ***http://sres.ciesin.org/final_data.html***

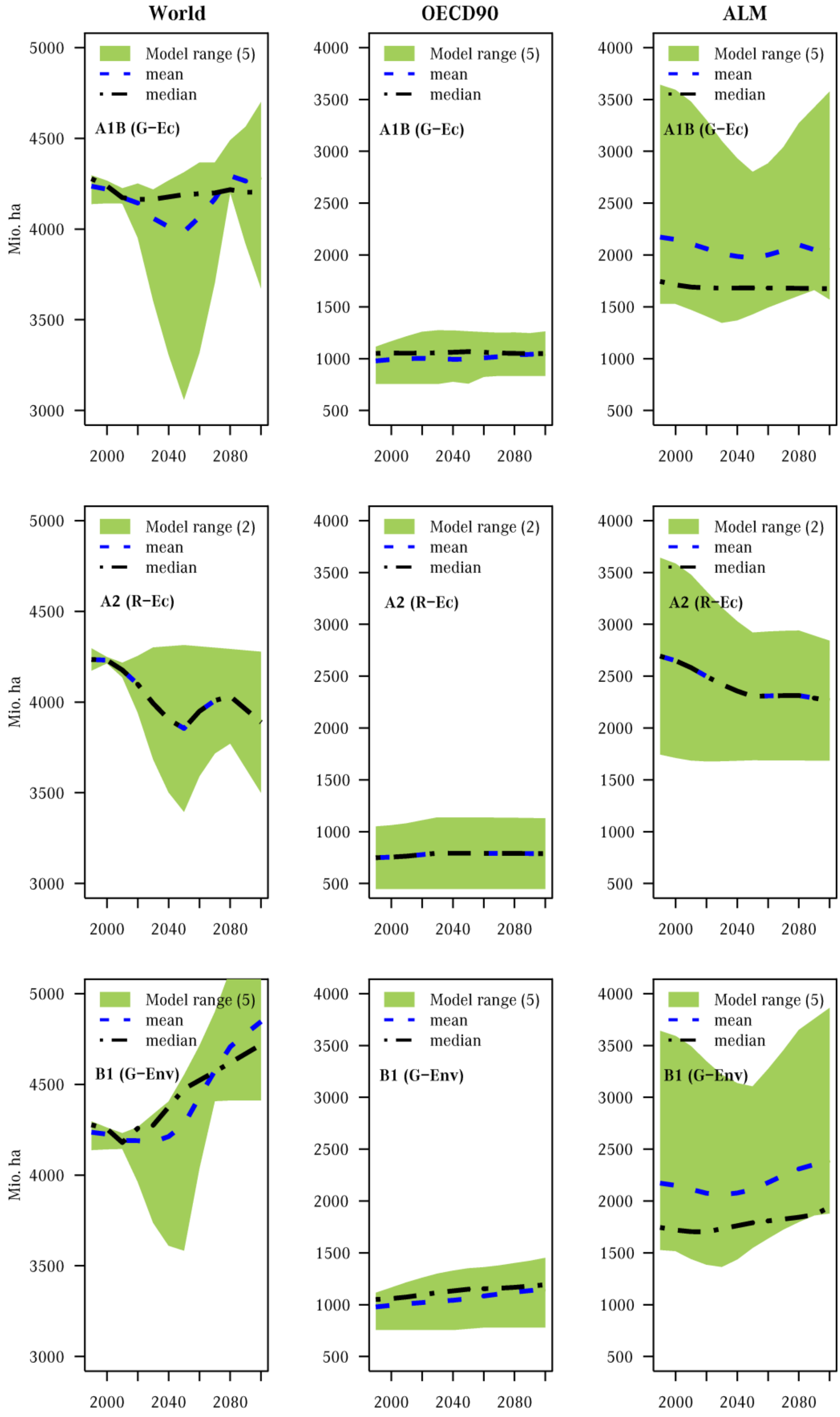


Figure 2.3. *Projections of Forest Area. Data source: http://sres.ciesin.org/final_data.html*

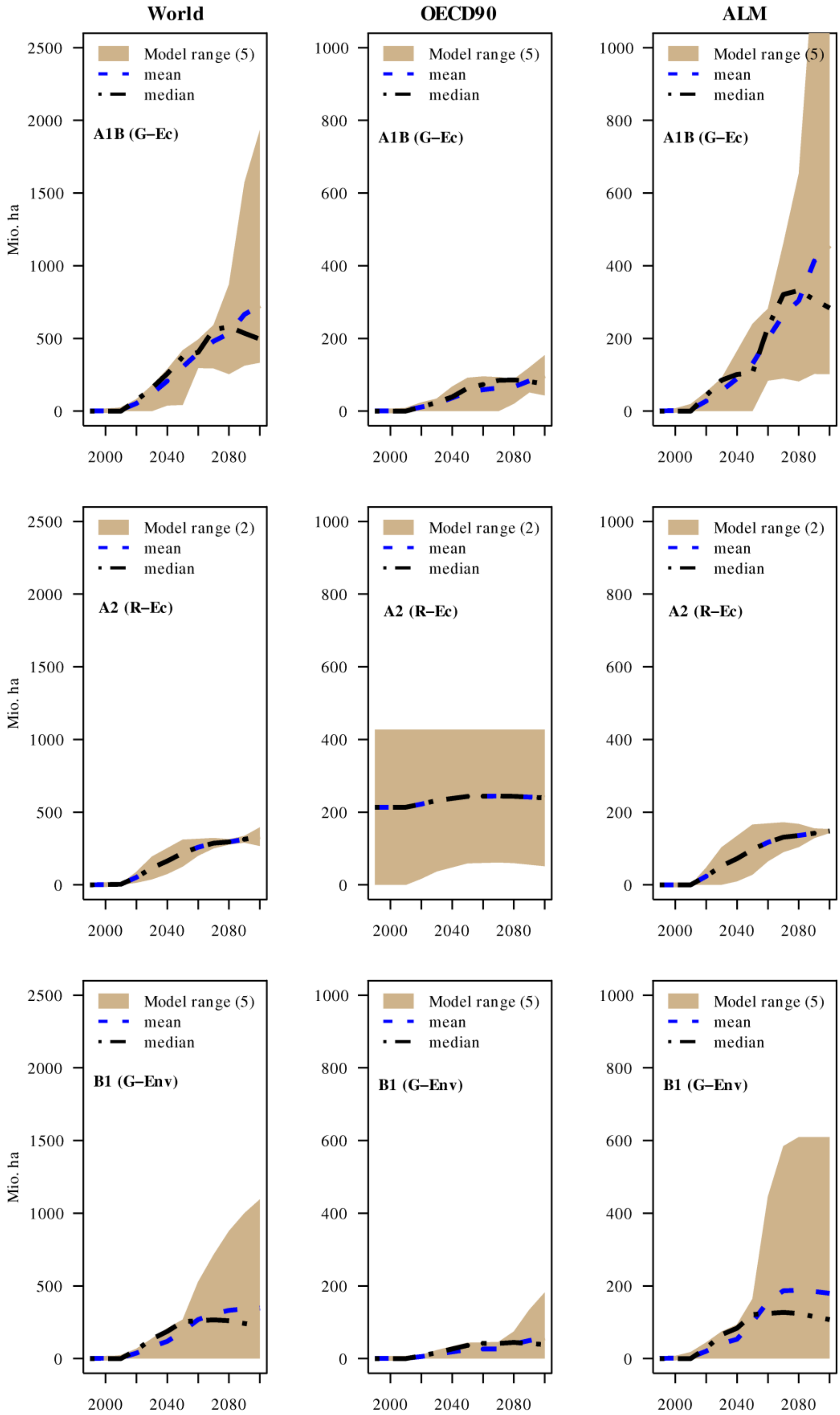


Figure 2.4. *Projections of Energy Biomass Area. Data source: http://sres.ciesin.org/final_data.html*

2.3.1.2 Socio-Economic Development

In contrast to the land use change projections, there is much higher agreement between the six assessment models for population development. The A1B (G-Ec) and B1 (G-Env) scenarios assume similar world population development with a peak in mid-century (~9 billion people) and a decline thereafter (see Figure 2.5). This trend is also projected for the ALM region, whereas population development in OECD90 countries is assumed to increase also after 2050 but at smaller growth rates. In all scenarios the average growth rates in the ALM region are much higher than in OECD90 countries. In the two globalization scenarios the growth rates between 1990 and 2050 are, with 30.4 Million people per year, eight times higher than in OECD90 countries (3.69 Million people per year). In the regionalization scenario the average growth rates are projected to be nine times higher in the ALM region than in the OECD90 region. The A2 (R-Ec) scenario projects an almost linear trend in world population growth, from ~6 billion in the year 2000 to ~15 billion at the end of the 21st century.

Figure 2.6 illustrates projections of total GNP/GDP development for the three SRES regions. The A1B (G-Ec) scenario shows by far the highest growth rates of all scenarios. At the end of the 21st century total GNP/GDP is projected to be higher in the ALM region than in the OECD90 region in the two globalization scenarios (A1B/G-Ec and B1/G-Env). In the A2 (R-Ec) scenario GNP/GDP is projected to be equal between OECD90 and ALM countries. But note, that these are projections of total GNP/GDP. If we take population development into account and look at the GNP/GDP per capita instead of total GNP/GDP per region, the picture looks very different. As shown in Figure 2.7, the highest GNP/GDP per capita growth rates denotes the A1B (G-Ec) scenario, with an average growth rate of 817 US$ per capita and year in OECD90 countries and 533 US$ in the ALM region. In the B1 (G-Env) scenario average yearly GDP growth rates per capita are 514 US$ in OECD90 countries and 371 US$ in ALM countries. The average GDP growth rates are the lowest in the A2 (R-Ec) scenario, with 332 US$ per capita and year in OECD90 countries and 118 US$ in the ALM region. This scenario projects lower GDP growth rates for OECD90 countries than for the ALM regions in the two globalization scenarios.

The ratio of GDP per capita growth rates between the developing world (ALM region) and OECD90 countries (GDP growth ALM * 100 / GDP growth OECD90) can be considered as an indicator for the level of convergence between these two world regions. The highest ratio (72%) is projected for the B1 (G-Env) scenario, followed by the A1B (G-Ec) scenario with 65%, whereas the ratio in the A2 (R-Ec) scenario is only 36%. This might lead to the conclusion that the level of convergence is highest in the A1B (G-Ec) scenario and the lowest in the A2 (R-Ec) scenario. In reality, there is further divergence between OECD90 and ALM countries in all scenarios, because, although all regions denote increasing GDP growth rates, the pace of GDP per capita increase is higher in the developed world than in the developing world. Hence, we should conclude that the level of divergence between OECD90 and ALM countries is decreasing in the scenarios in the following order: 1. B1 (G-Env); 2. A1B (G-Ec); 3. A2 (R-Ec). The red line in Figure 2.7 shows the average differences of GDP development per capita and year between OECD90 and ALM countries (GDP per capita and year OECD90 minus GDP per capita and year ALM). In the A1B (G-Ec) scenario there was a difference of ~17,000 US$ GDP per capita per year in the base year 1990 between ALM and OECD90 countries. The difference projected for the year 2100, following an almost linear trend, is ~47,000 US$ per capita and year. In the A2 (R-Ec) scenario the trend is similar but the final difference in 2100 is “only” ~40,000 US$. The GDP gap increases in both scenarios! The B1 (G-Env) scenario is the only scenario where a real convergence trend is projected starting in mid-century. Up to 2060 there is an ongoing increase of divergence in GDP per capita and year between ALM and OECD90 countries, from ~17,000 US$ (1990) to ~35,000 US$ (2060). The period between the years 2060 and 2100 projects a trend of real convergence between ALM and OECD90 countries, where the difference of GDP per capita and year decreases from ~35,000 to ~30,000 US$.

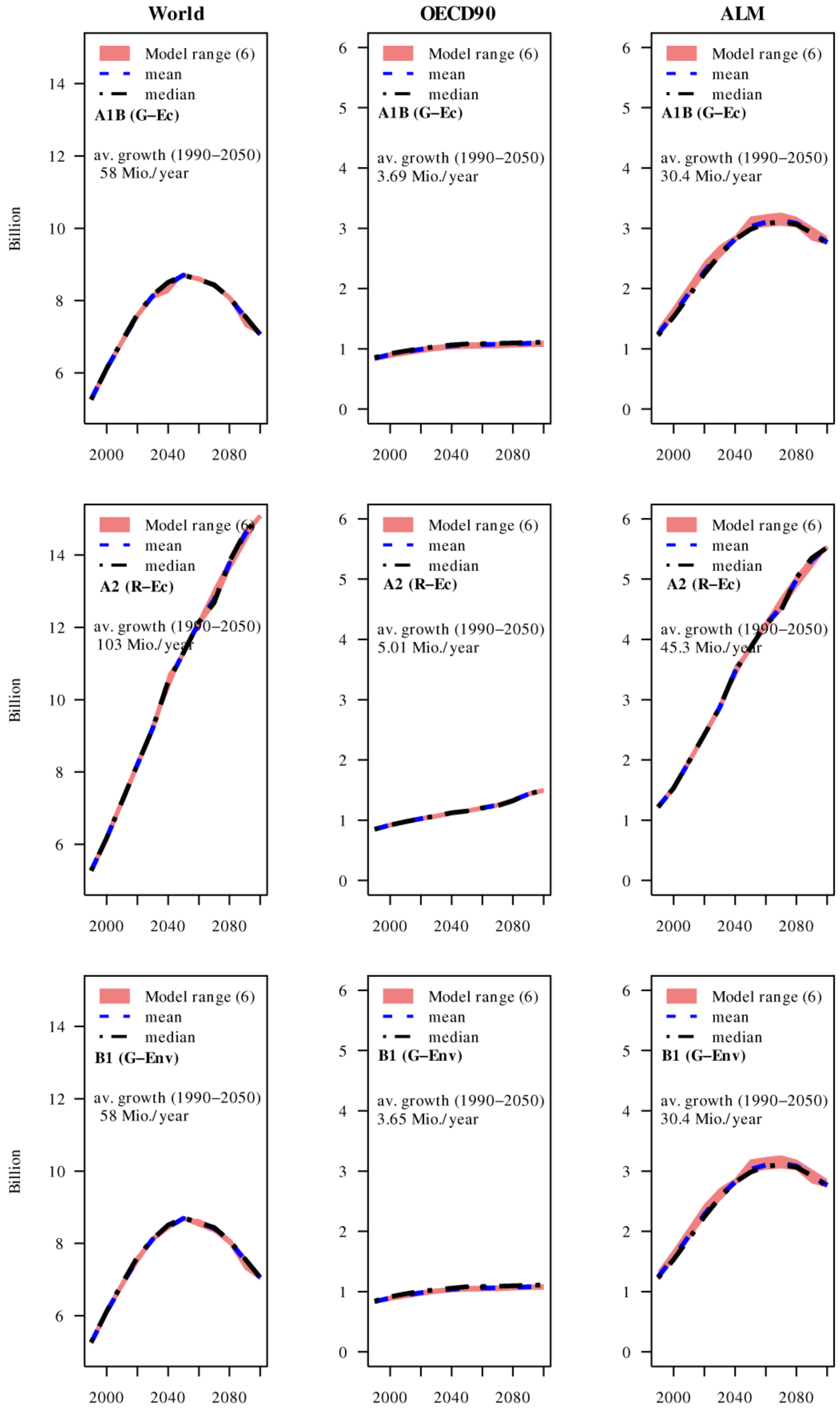


Figure 2.5. *Projections of Population Development*

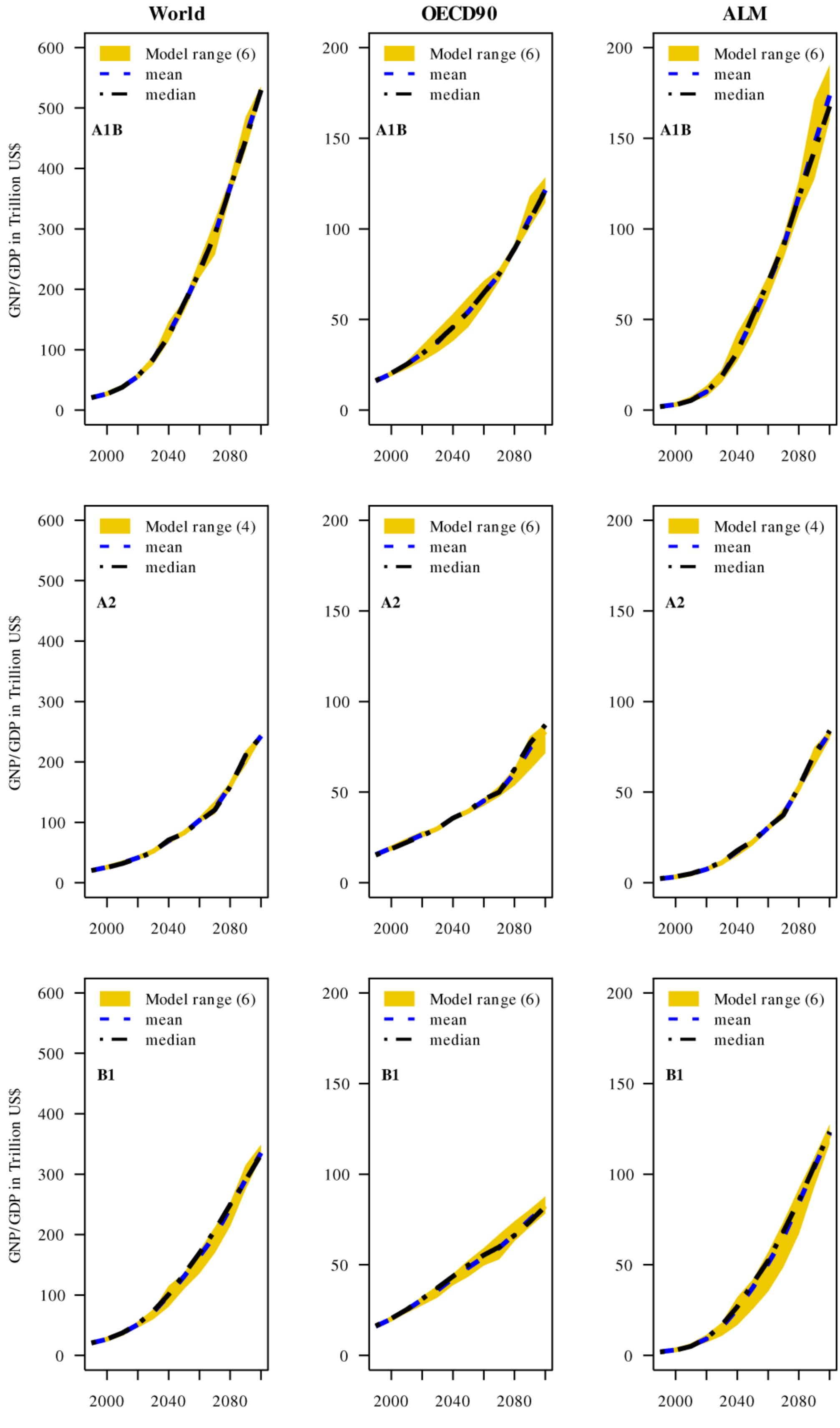


Figure 2.6. *Projections of Total GNP/GDP per SRES Region. Data source: http://sres.ciesin.org/final_data.html*

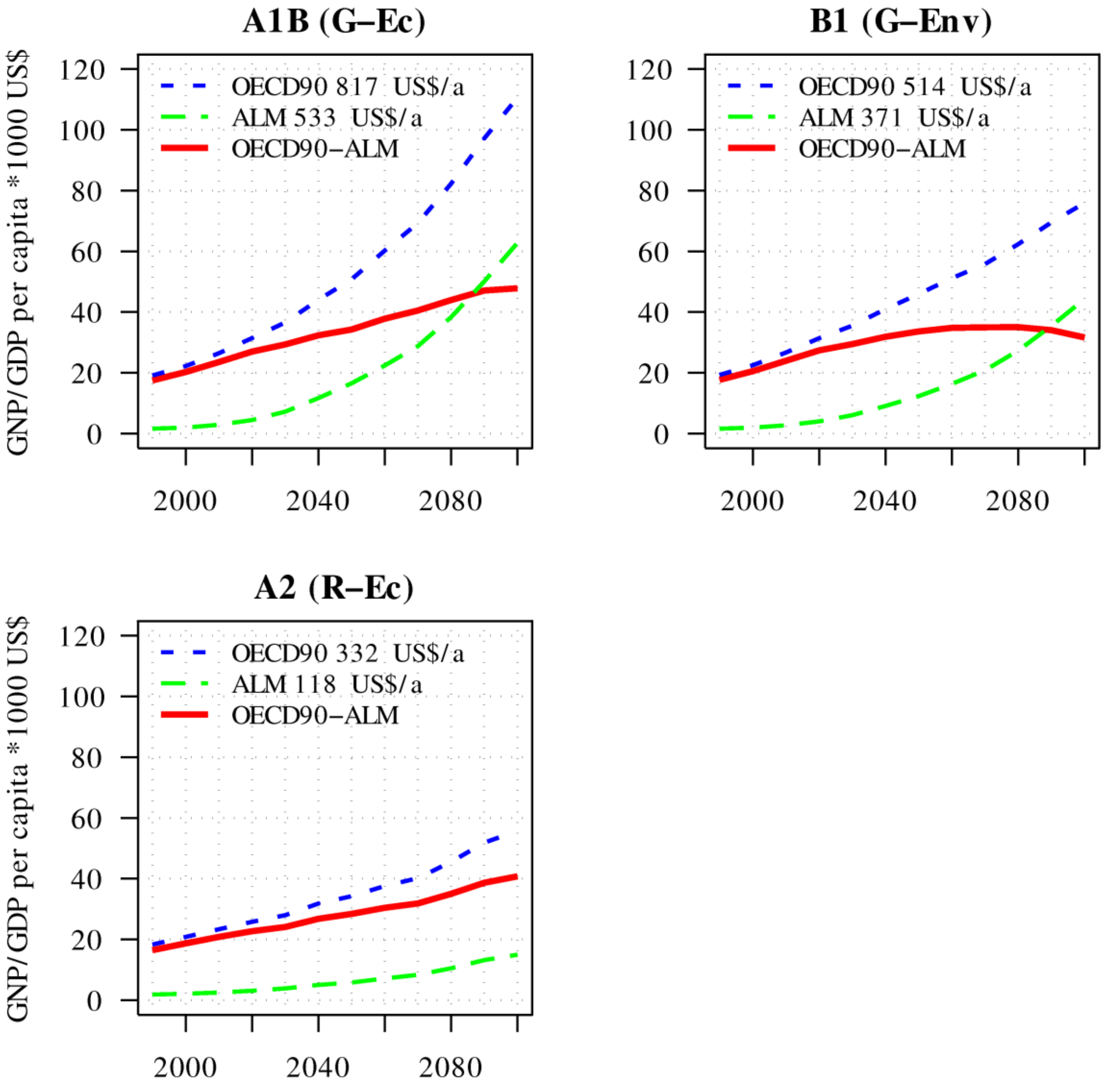


Figure 2.7. *GDP per Capita, Convergence or Divergence between OECD90 and ALM? Data source: http://sres.ciesin.org/final_data.html*

2.3.1.3 Energy Consumption

Figure 2.8 shows the future trends of total energy consumption and the share of renewable energy. The units are in Exajoule (1 EJ = 10^18 J). Total world energy consumption is projected to continuously increase in the A1B (G-Ec) and A2 (R-Ec) scenarios up to the end of the 21st century. The B1 (G-Env) scenario assumes increasing energy consumption up to mid-century and shows decreasing trends thereafter. The share of global renewable energy to total energy at the end of the 21st century is approximately 45% in the scenarios A1B (G-Ec) and B1 (G-Env), whereas the share in the A2 (R-Ec) scenario is projected to be ~20% only. It is worth noting that the A1B (G-Ec) scenario is the scenario with the highest energy consumption in 2100, although projected world population is only the half of the A2 (R-Ec) scenario at the end of the century. However, the uncertainties related to the projections of energy consumption, produced by the six assessment models, is rather large in the A1B (G-Ec) scenario. In both scenarios the energy consumption in OECD90 countries increases with almost similar patterns and the ALM region denotes very high total energy consumption rates. The highest consumption rates for the ALM region are obtained in the A1B scenario. This might be a consequence of the rapid introduction of technology and increasing living standards in the developing world in this scenario.

In the previous sub-section the level of convergence among SRES regions was assumed to be a function of GDP per capita development. If we use the per capita energy consumption as a measure to define convergence or divergence, respectively, the conclusions are slightly different. Figure 2.9 shows projected per capita energy consumption and their average growth rates in the three world regions. The two scenarios with a focus on economy (A1B/G-Ec and A2/R-Ec) project an increase of per capita energy consumption for all regions. The A1B (G-Ec) scenario shows by far the highest growth rates per capita and year (World = 2.2 GJ, OECD90 = 1.2 GJ, and ALM = 2.2 GJ). Global per capita energy consumption is projected to be almost three times higher than in the other two scenarios. However, a trend toward convergence between OECD90 and ALM countries can be denoted in the A1B (G-Ec) scenario, starting with a difference of ~150 GJ per capita in the base year 1990 and ending up with a difference of ~70 GJ in 2100. The strongest convergence according to the per capita energy consumption achieves the B1 (G-Env) scenario with 161 GJ in 1990 to 59 GJ in 2100. In contrast to this convergence trend in the globalization scenarios, the projections of energy consumption differences in the A2 (R-Ec) scenario increase from 158 GJ (1990) to 190 GJ in 2100.

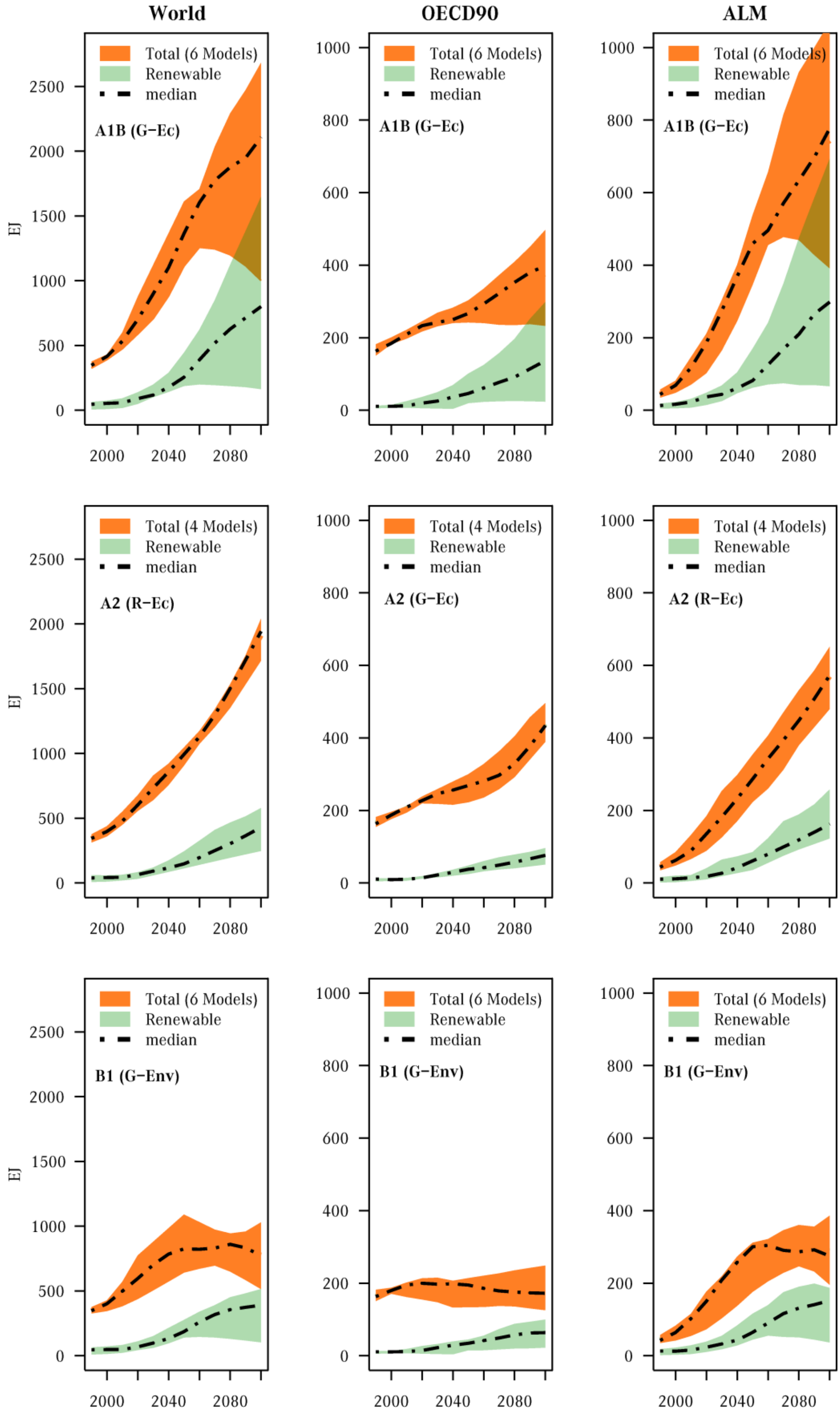


Figure 2.8. *Consumption Projections of Total and Renewable Energy. Data source: http://sres.ciesin.org/final_data.html*

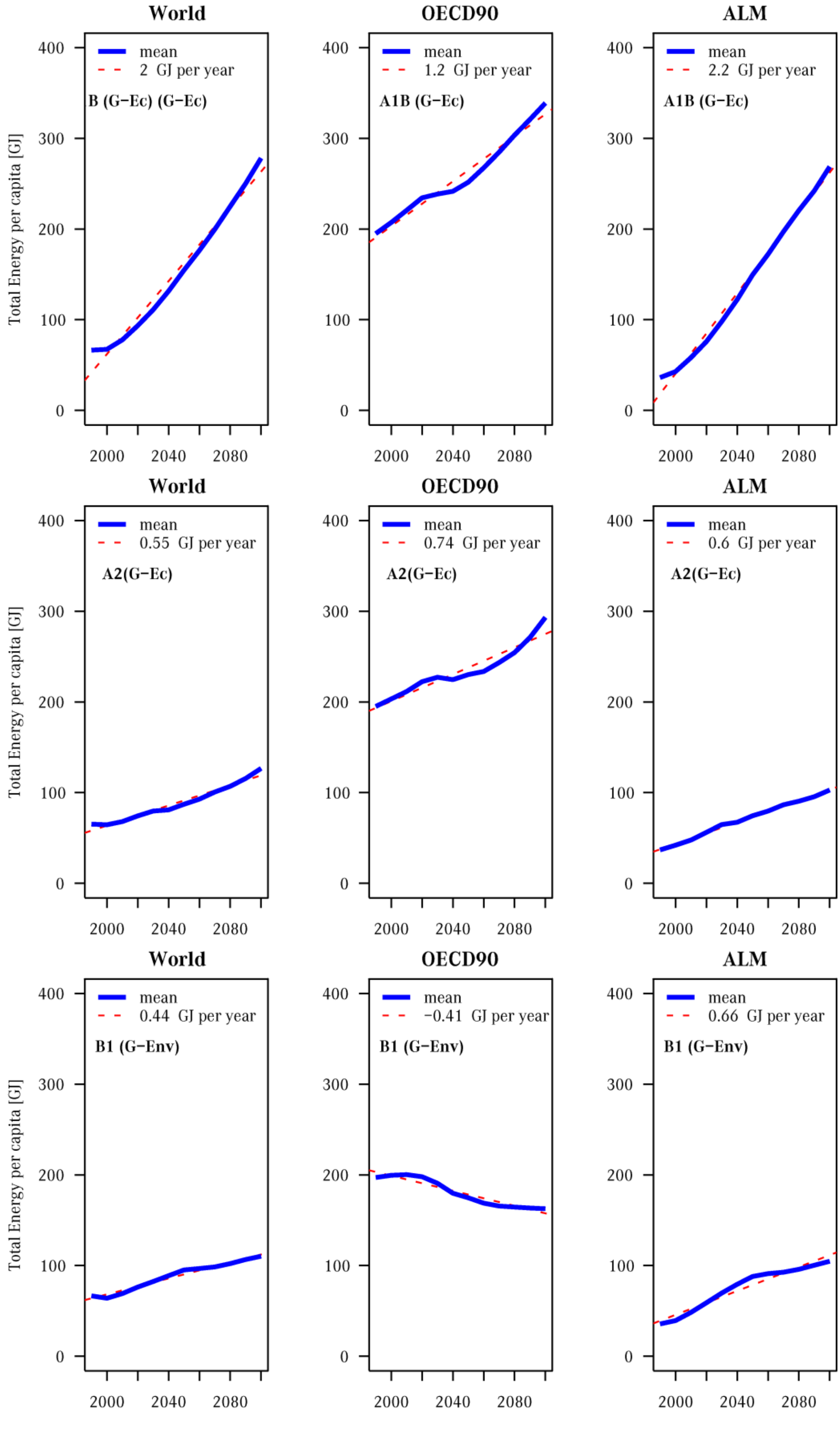


Figure 2.9. *Total Energy Consumption per Capita. Data source: http://sres.ciesin.org/final_data.html*

2.3.2 Downscaled Data to Country Level

Aggregated population and GDP data used in the SRES report have been downscaled to the country level by CIESIN (2002), Van Vuuren et al. (2007), and Grübler et al. (2007). A description of the downscaling methods used by CIESIN (2002) and corresponding data are available at: http://www.ciesin.columbia.edu/datasets/downscaled/. Van Vuuren et al. (2007) used an external-input-based downscaling algorithm to downscale population data and a convergence-based downscaling method for GDP (per capita income levels) at the national level. Corresponding data are available from the authors. The downscaling method used by Grübler et al. (2007) is described in their article and corresponding data are available at IIASA (2007).

2.3.2.1 Population

The population directly influences the consumption of goods and emission levels and is thus an important driver of global environmental change. However, the IPCC-SRES scenarios are not longer fully reflecting current insights into possible future demographic trends (van Vuuren & O'Neill, 2006). Future population growth depends on a countries' phase of demographic transition. Many low-income countries are still in the transitional phase with a relatively young age structure. “The age profile of a population is one of the crucial factors in future population growth and represents a major reason for not applying linear downscaling to population projections” (Van Vuuren et al., 2007).

The following charts illustrate population development at the country level for the four southern WETwin case study countries. Projections for the A2 scenario from IIASA (2007) correspond to the A2r scenario. IIASA (2007) data between decades have been linearly interpolated since they are available from 2000 to 2100 for each decade, whereas data from Van Vuuren (2007) and CIESIN (2002) are provided in five year steps between 1990 and 2100.

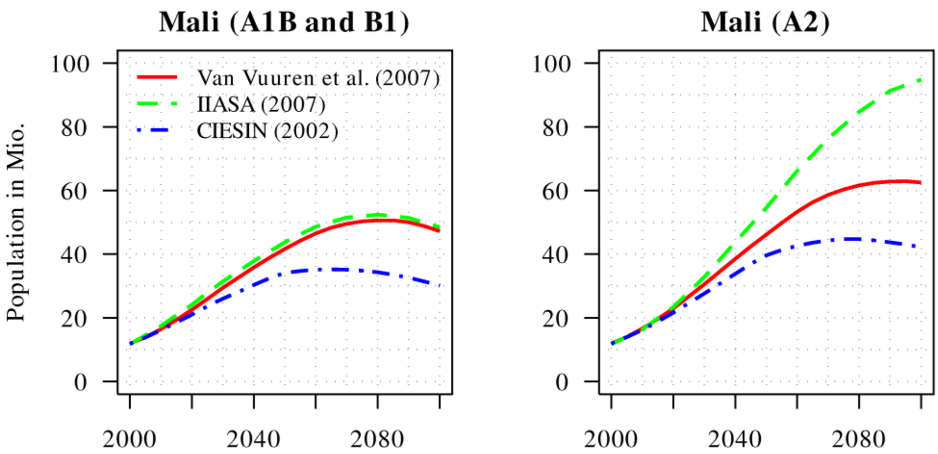


Figure 2.10. *Population projections for Mali from three different sources*

Mali’s population in 2009 was 13.4 million and the population growth rate is ~2.6% (CIA, 2010). Assuming a constant growth rate of 2.6% results in a population increase to 38.4 million people in 2050. Figure 2.10 shows exactly this trend for the A1B and B1 scenarios whereas Van Vuuren et al. (2007) and IIASA (2007) assume much more rapid increases for the A2 scenario. According to CityMayors (2010), Bamako, the capital of Mali with 1.8 million inhabitants, is currently estimated to be the fastes growing city in Africa and the sixth fastest in the world (wikipedia.org). The projected average annual population growth for the period 2006 to 2020 is 4.45%.

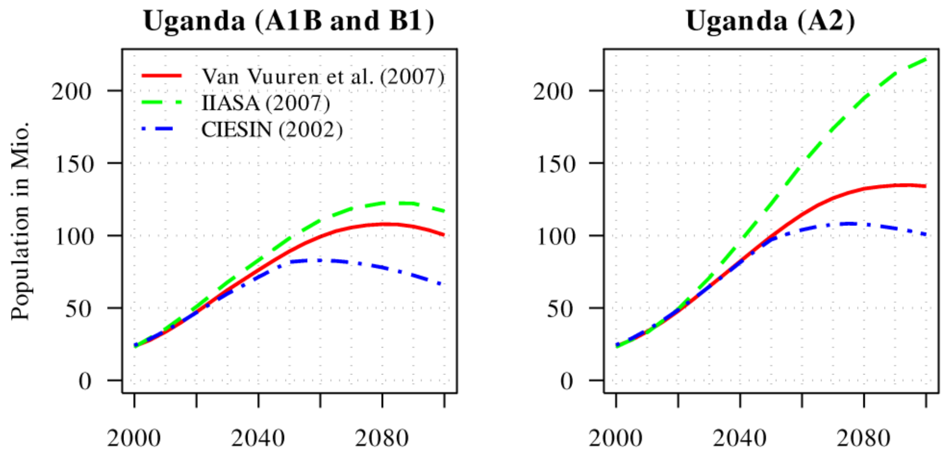


Figure 2.11. *Population projections for Uganda from three different sources*

Uganda's population in 2009 was 32.4 million and the population growth rate is ~2.7% (CIA, 2010). Assuming a constant growth rate of 2.7% results in a population increase to 96.6 million people in 2050. This assumption is in line with the projections shown in Figure 2.11 for the A1B and B1 scenarios. The projections of Van Vuuren et al. (2007) and CIESIN (2002) show almost the same trend for the A2 scenario (up to 2050) whereas the projections of IIASA (2007) assume a population increase up to 125 million people in 2050.

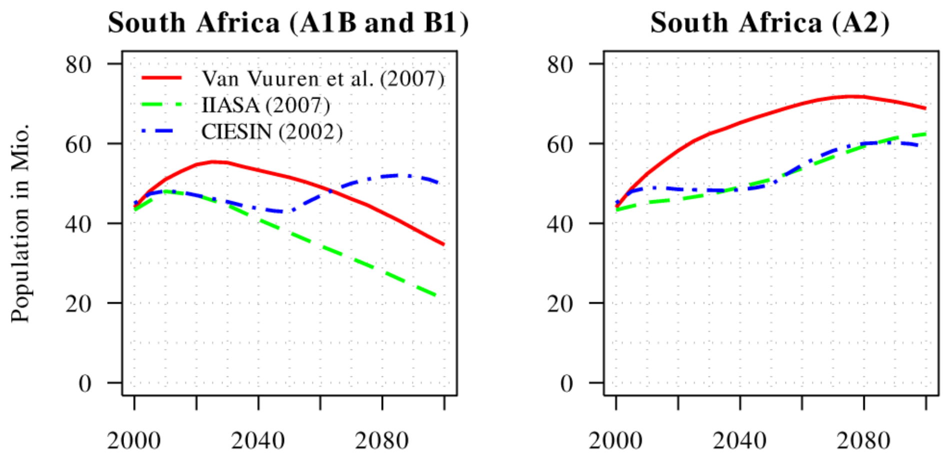


Figure 2.12. *Population projections for South Africa from three different sources*

The population of South Africa was 49 million in 2009 (CIA, 2010) and the growth rate is 0.28%. Following a constant growth rate the population in 2050 would increase to 55 million people. However, the projections for the A1B and B1 scenario are not in line with the assumption of a constant growth rate. IIASA (2007) and CIESIN (2002) assume a decreasing trend up to 2050 resulting in population decrease to approximately 40 million people (Figure 2.12). Van Vuuren et al. (2007) project an increase up to the year 2025 (55 million) and a decline thereafter with a population of 51 million in 2050. For the A2 scenario IIASA (2007) and CIESIN (2002) project a population increase to approximately 50 million in 2050 whereas Van Vuuren et al. (2007) assume an increase to 68 million in 2050.

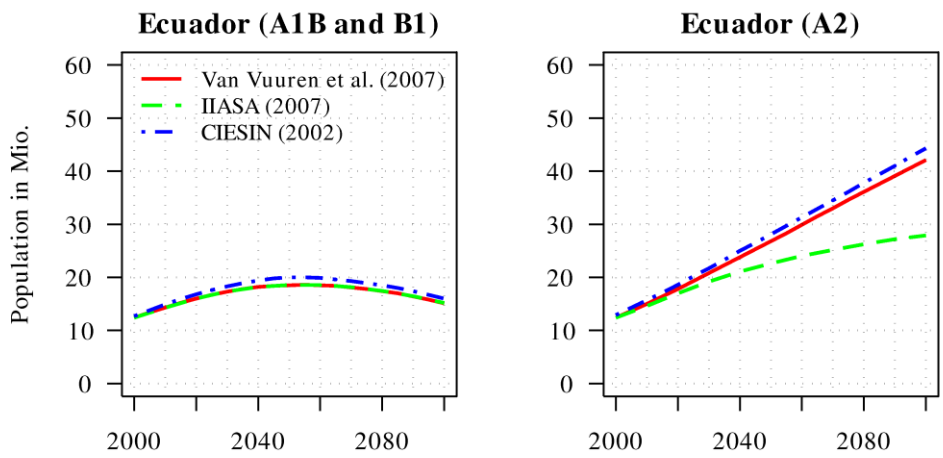


Figure 2.13. *Population projections for Ecuador from three different sources*

According to CIA (2010), the population of Ecuador was 14.6 million in 2009 and the growth rate was 1.5%. Assuming a constant growth rate of 1.5% would result in a population increase to 26.9 milion people in 2050. The same trend is assumed by Van Vuuren et al. (2007) and CIESIN (2002) for the A2 scenario, whereas IIASA (2007) projects an increase to approximately 23 million people in 2050 (Figure 2.13). The projections for the A1B and B1 scenarios assume a slower population increase up to 20 million people in 2050. Moreover, the projections show a decline of population after 2050.

2.3.2.2 GDP

The results of the methodology applied by van Vuuren et al. (2007) do not achieve improbable high income levels, as in the method used by Gaffin et al. (2004). Countries starting with a relatively large per capita income have lower income growth rates than countries starting with a relatively low per capita income. This is consistent with both the literature on conditional convergence and the scenario storylines (van Vuuren et al., 2007).

The following charts illustrate the GDP development per capita at the country level for the four southern WETwin case study countries. Projections for the A2 scenario from IIASA (2007) correspond to the A2r scenario. GDP data provided by IIASA (2007) are aggregated to the country level. In order to compare these projections with per capita data produced by Van Vuuren et al. (2007), they were divided by the projected population (IIASA, 2000) in the respective year. Furthermore, IIASA (2007) data between decades have been linearly interpolated since they are available from 2000 to 2100 for each decade, whereas data from Van Vuuren (2007) are provided in five year steps between 1990 and 2100.

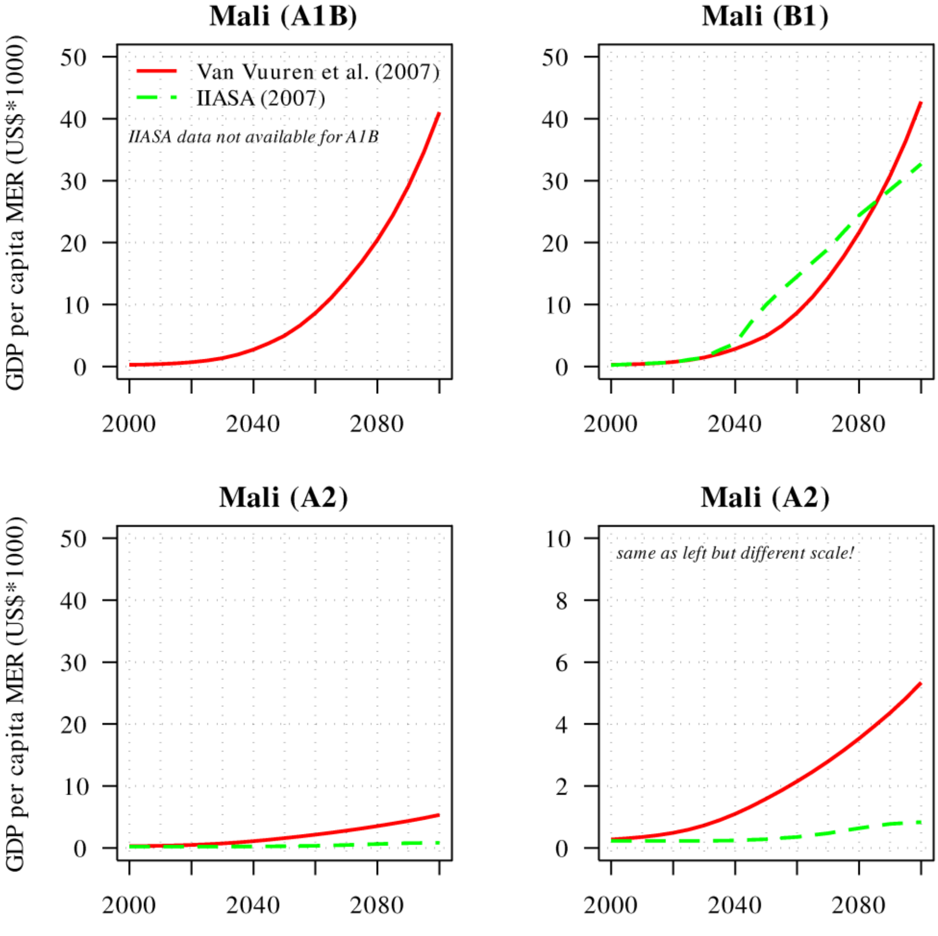


Figure 2.14. *GDP per capita projections for Mali*

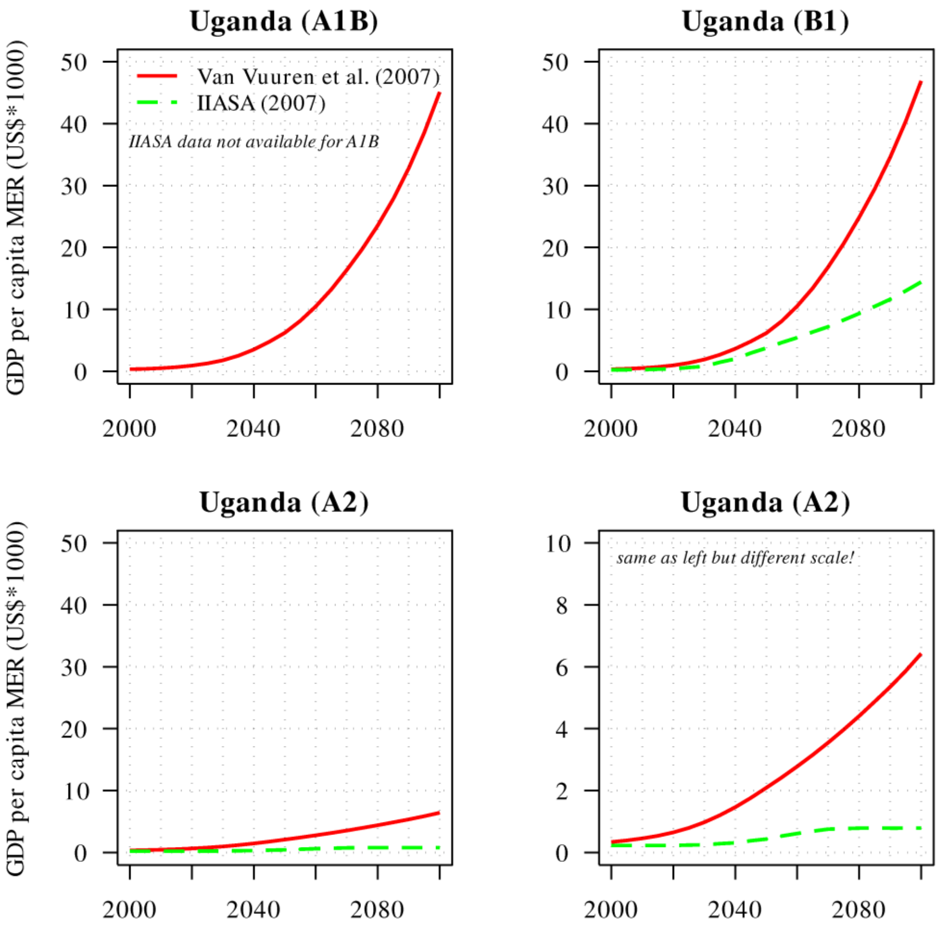


Figure 2.15. *GDP per capita projections for Uganda*

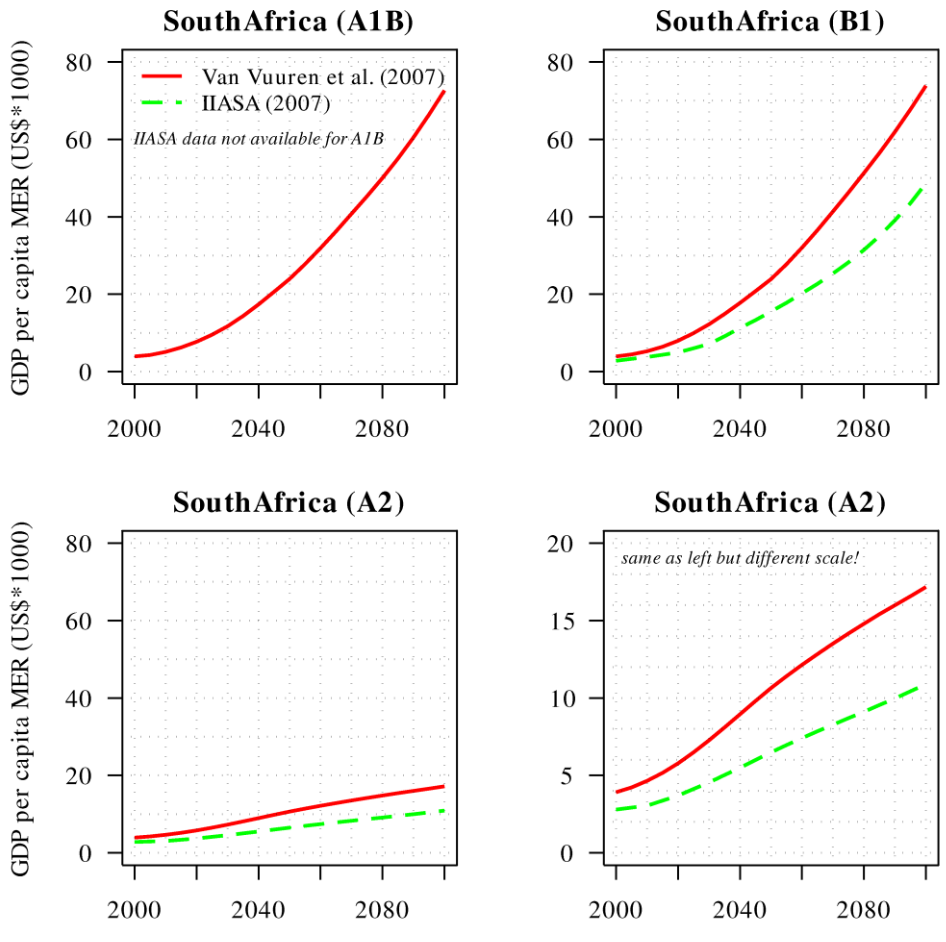


Figure 2.16. *GDP per capita projections for South Africa*

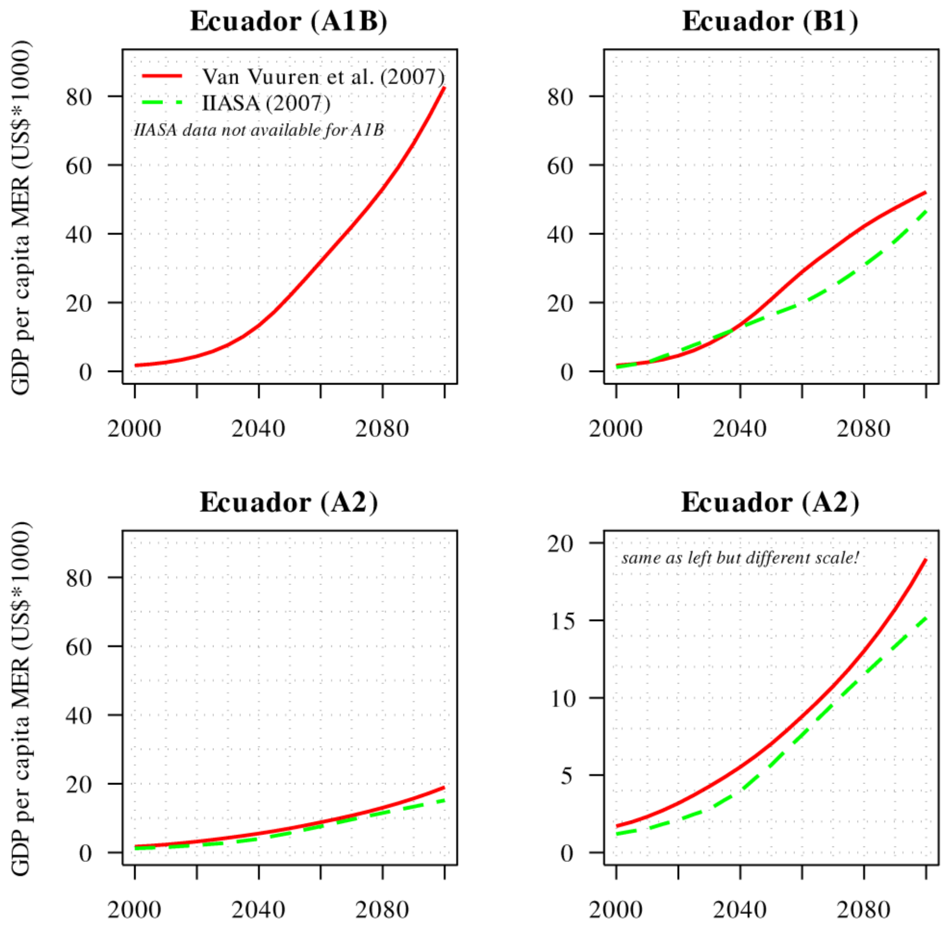


Figure 2.17. *GDP per capita projections for Ecuador*

2.4 Climate Projections

2.4.1 Regional Scale

The Figure 2.18 and Figure 2.19 show a very preliminary and rough assessment of temperature and precipitation projections for the WETwin case study countries. The data source were maps of climate change over the period 2000 to 2050 simulated by three Global Climate Models (GCM's), MPI ECHAM5, UKMO Had CM3, and NCAR CCSM-3. The figures show the model mean and model range for the A1B, A2, and B1 SRES scenarios. Hence, the figures do not differentiate between the SRES scenarios, but show the maximum range of all scenarios. Figure 2.20 and Figure 2.21, borrowed from IPCC (2007), complement this assessment but are based on a different time frame (comparing the last two decades of the 20th century with projections for the last two decades of the 21st century).

Figure 2.18 shows temperature projections for the southern case study countries. Increasing temperatures are projected for all regions. Compared to the temperatures in the base year 2000, an increase of up to two degrees can be expected in 2050 for Mali, Uganda, and Ecuador. The projections shown in Figure 2.20 and Figure 2.21 approve this tendency. The same trend is projected for South Africa, but the uncertainties shown by the model range is much higher than in the other cases, where the worst case indicates an increase of four degrees. However, further investigations will aim at differentiating the projections for the three SRES scenarios.

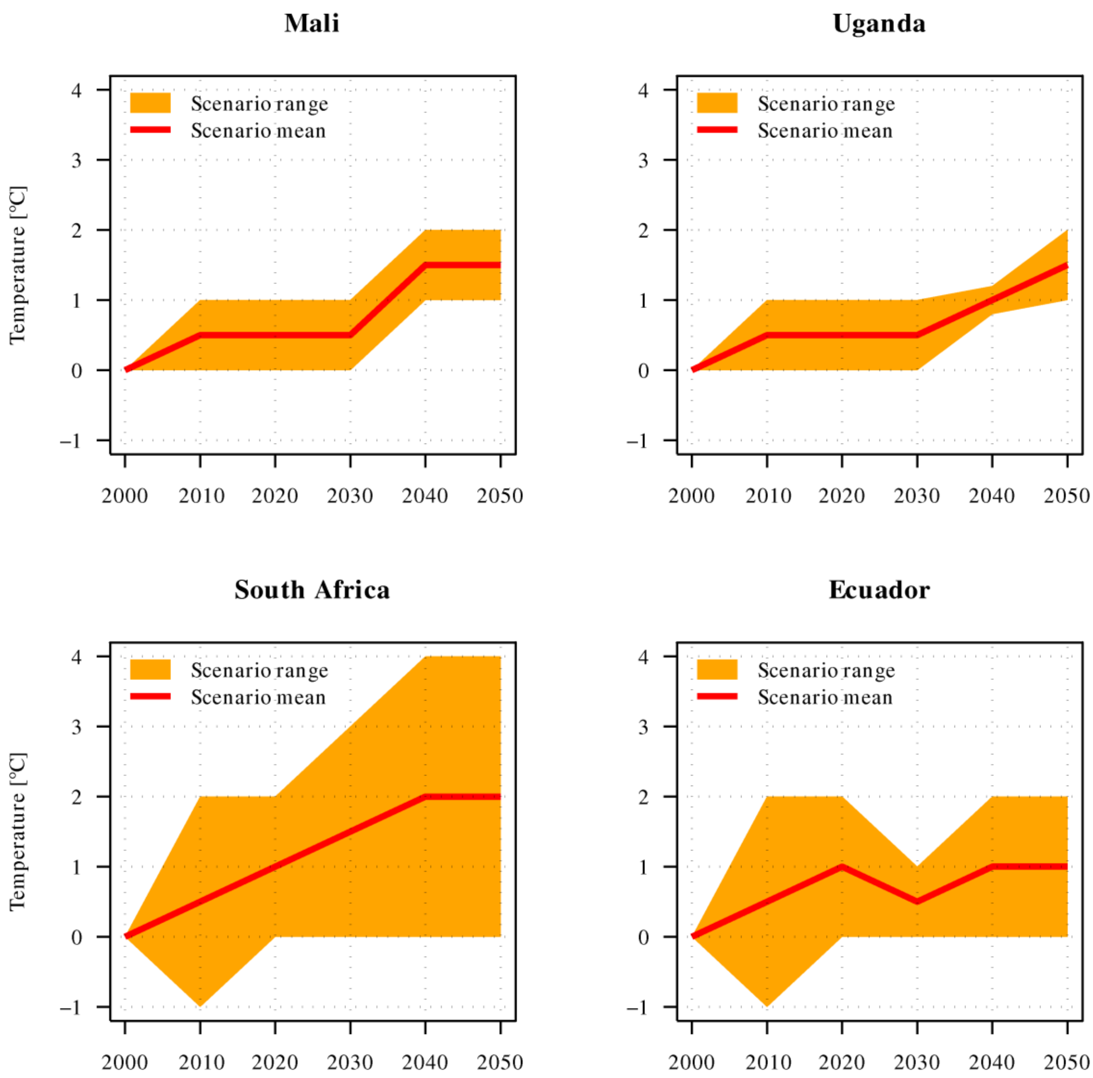


Figure 2.18. *Temperature Projections (Data Source: GCM's: MPI ECHAM5, UKMO Had CM3, NCAR CCSM-3)*

As illustrated in Figure 2.19, uncertainties related to precipitation projections are even higher than for temperature. Again, the large uncertainty range is on the one hand due to the rapid assessment method based on visual analysis of climate change maps and on the other hand it is a matter of fact that precipitation projections are considered to be subject to higher uncertainties than temperature projections. Nevertheless, what can be learned from figures 2.19, 2.20, and 2.21 is that the probability to more wetness in East Africa (Uganda) and in Ecuador is projected to increase. Furthermore, there is no obvious trend projected for Mali but a slight tendency to decreasing precipitation in South Africa.

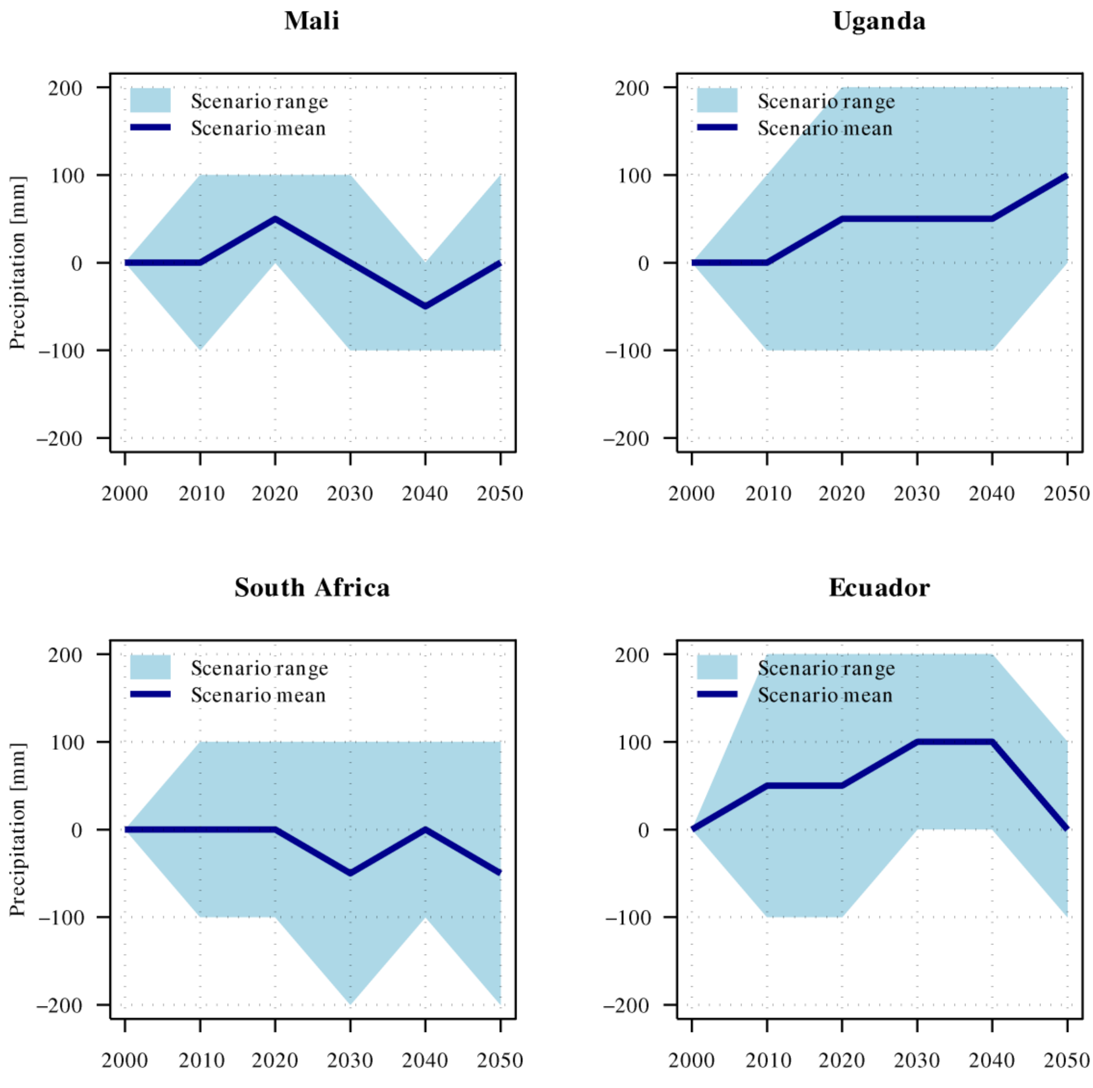


Figure 2.19. *Precipitation Projections (Data Source: GCM's: MPI ECHAM5, UKMO Had CM3, NCAR CCSM-3)*

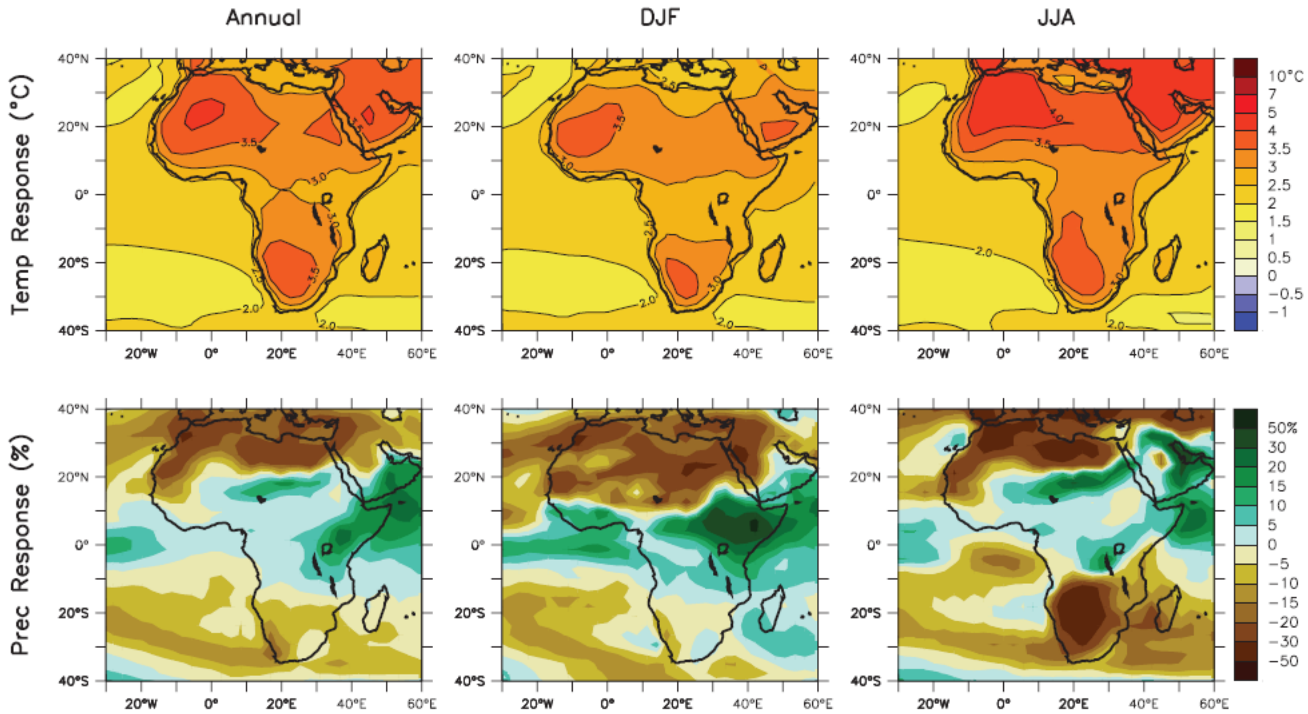


Figure 2.20. *Temperature and precipitation changes over Africa from the MMD-A1B simulations. Top row: Annual mean, DJF and JJA temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Bottom row: same as top, but for fractional change in precipitation (IPCC, 2007)*

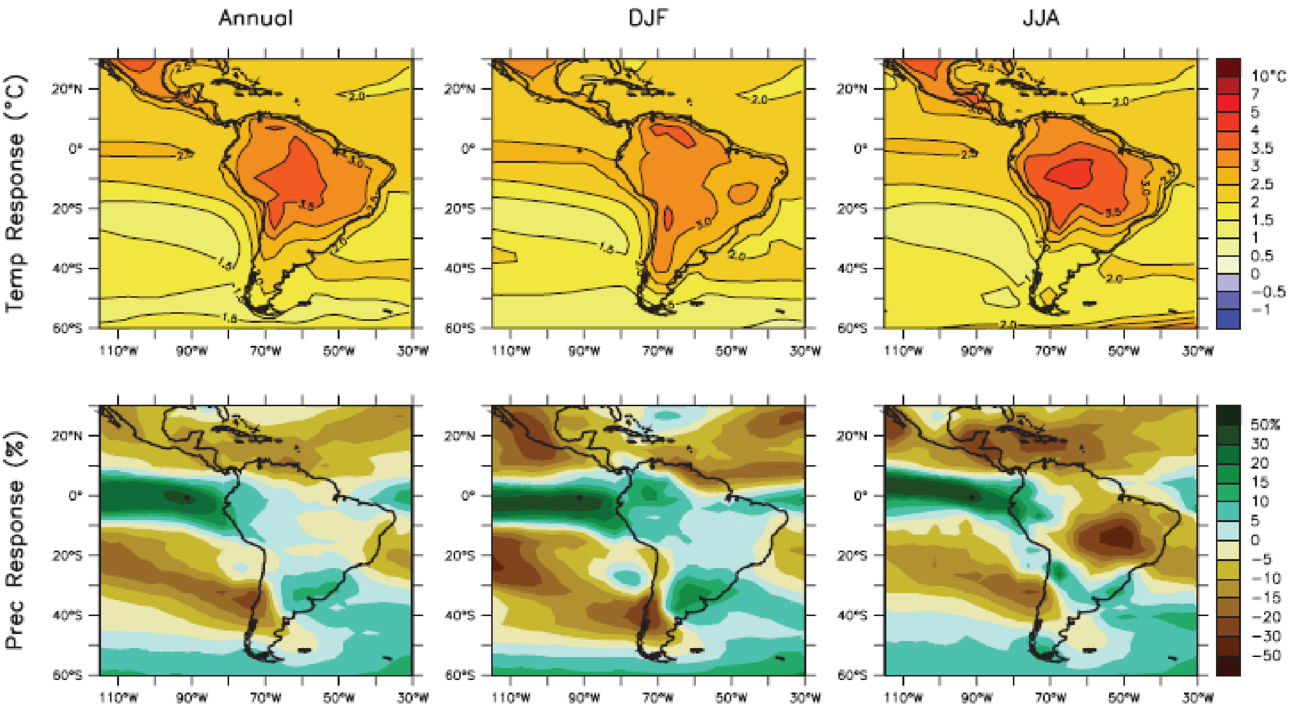


Figure 2.21. *Temperature and precipitation changes over South America from the MMD-A1B simulations. Top row: Annual mean, DJF and JJA temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Bottom row: same as top, but for fractional change in precipitation (IPCC, 2007)*

2.4.2 Case Study Scale

The following Figures (2.22 to 2.26) have been produced on the basis of the work of Österle & Böhm (2009) and Hirabayashi et al. (2008). Figure 2.27 only on the basis of Hirabayashi et al. (2008). Österle & Böhm (2009) developed daily temperature and precipitation data for entire Africa in 0.5° resolution for the period from 1958 to 2007. Their general method is documented in a contribution to a German climate conference, but was slightly adapted in order to produce the African dataset. Hirabayashi et al., (2008) produced a daily global dataset of various climate parameters in 0.5° resolution. Where the precipitation dataset seems to consist of rather “reliable” data, the temperature dataset obviously contains anomalies in several grid cells and some years. However, for the Ecuadorian case study only the dataset of Hirabayashi et al., (2008) was available. In the following we call the datasets produced by Österle & Böhm (2009) and Hirabyashi et al. (2008) “observed”, although they have been modeled, interpolated, derived from various sources, and additionally fed with measured data.

The following figures show “observed” and projected temperature and precipitation data of selected grid cells located in the southern WETwin case study areas. A linear trend over the observation period was estimated and is shown in the figures' legend. The slope of the trend lines indicates the average change rate per year in °C or mm and can be positive or negative. The projections for temperature follow this linear trend up to the year 2050. The amplitudes of the projection periods are only allowed to be within the same magnitude as in the observed period. Projecting precipitation data is much more difficult and uncertain. But also here a rather simple approach was applied to visualize possible future trends and ranges for the case study areas. Similarly to the method used for temperature data, the precipitation projections follow the linear trend as indicated by the observed period. But in order to better account for uncertainties related to precipitation projections, an opposite trend was additionally included and extents the projection range.

2.4.2.1 Mali

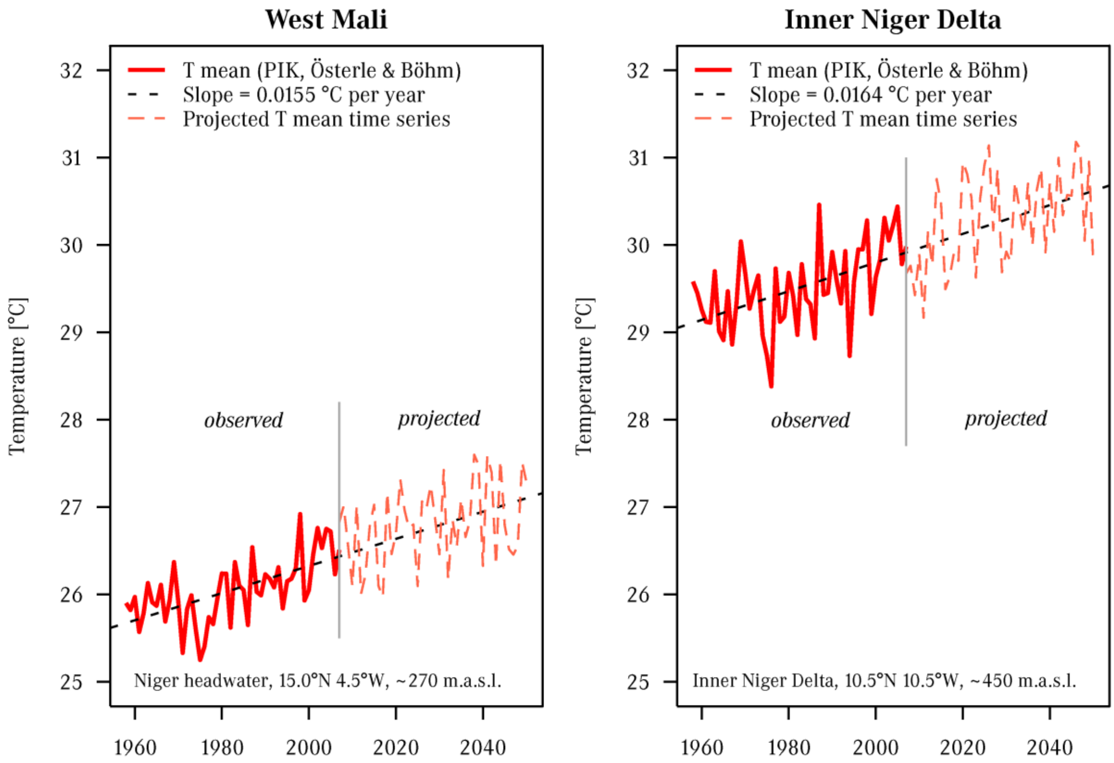


Figure 2.22. *Temperature, Observations and Projections, Data Source: Österle & Böhm (2009)*

Figure 2.22 shows temperature observations based on Österle & Böhm (2009) for two different sites (grid cells) in Mali. One is located in the Niger headwater region in West Mali and the other inside the Inner Niger Delta (IND). In order to better highlight the differences between both sites, similar temperature ranges are displayed on the y-axes. The wetland area is characterized by higher temperatures than the headwater region, more than three degrees in the annual average. Almost similar increasing temperature trends (~0.016 °C per year) were observed during the period from 1958 to 2007. Moreover, the temperature amplitude in the wetland area is higher (more extremes and variability) than in West Mali. According to the observed trend, temperature increases around 0.8°C within 50 years. Compared to the projections shown in Figure 2.18 and Figure 2.20 this is a rather conservative assessment and temperature is more likely to increase with a higher pace in future decades.

The rainfall patterns and trends in the two sites are very different. First of all, the Inner Niger Delta region is with an average annual amount of 338 mm much dryer than the location in West Mali (1300 mm/year).Figure 2.23 shows decreasing trends for both sites during the observation period, where the slope of the linear trend line in West Mali is with -8.6 mm/year much steeper than in the wetland area (-1.1 mm/year). Differentiating the observation period into sub-periods shows that the trend is not linearly declining in all sub-periods, rather it indicates extremely opposing trends (see Table 2.9). In the period between 1958 and 1984 rainfall decreased with a rate of 19.6 mm/year in West Mali. In contrast to this, the following period (1984-1994) was characterized by extremely increasing precipitation rates of 58.2 mm/year. The last period (1994-2007), however, shows again a very strong negative trend of rainfall (-48.6 mm/year). The precipitation trends in the Inner Niger Delta show exactly the same trends, but within lower magnitudes. Furthermore, the variability or variance of annual rainfall amounts is much higher in the last two periods (1984-2007) than in the first period.

Based on this analysis we conclude that it would be naive to project rainfall assuming only a linear trend derived from the past, because rainfall patterns showed a rather non-linear behavior. Hence, the projected uncertainty range is extended by a positive trend with a slope of +1 mm per year. Due to the strong negative trend in West Mali during the observed period the projections have a tendency to decreasing rainfall. Projections for the Inner Niger Delta, however, show no concrete trend. Taking the projected increase of temperature for West Mali and the wetland area into account, together with a decreasing precipitation trend in the headwater area, the probability of water scarcity problems is more likely to increase in the future.

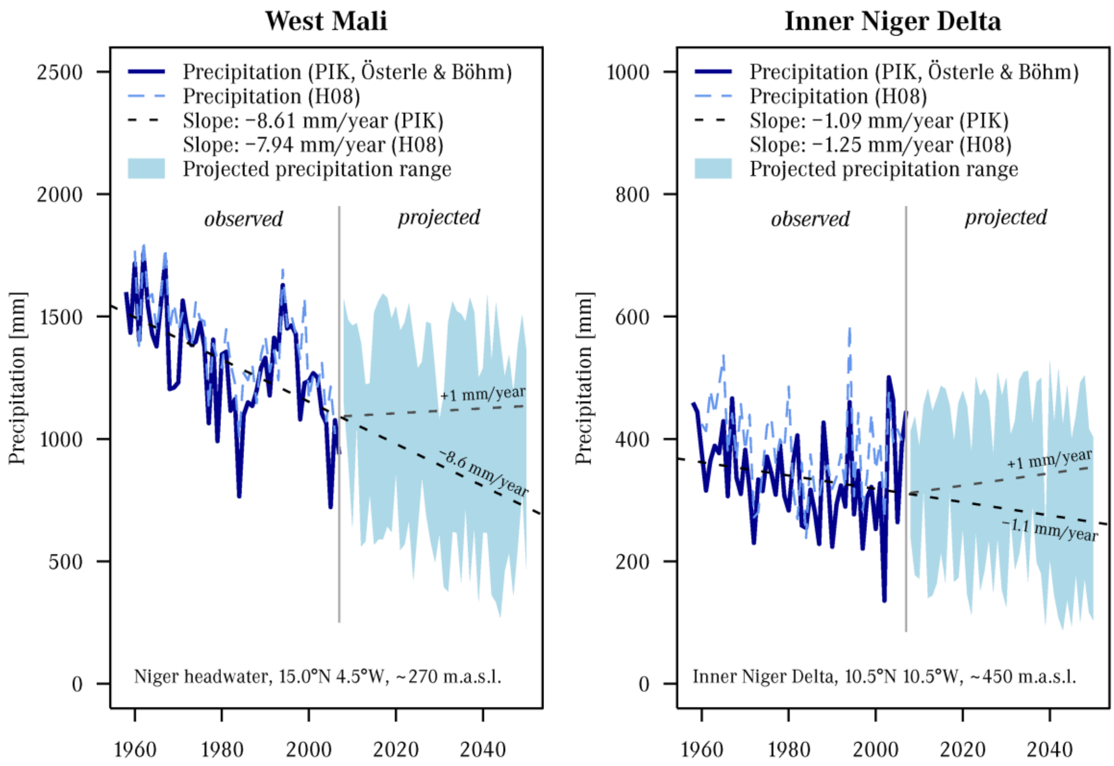
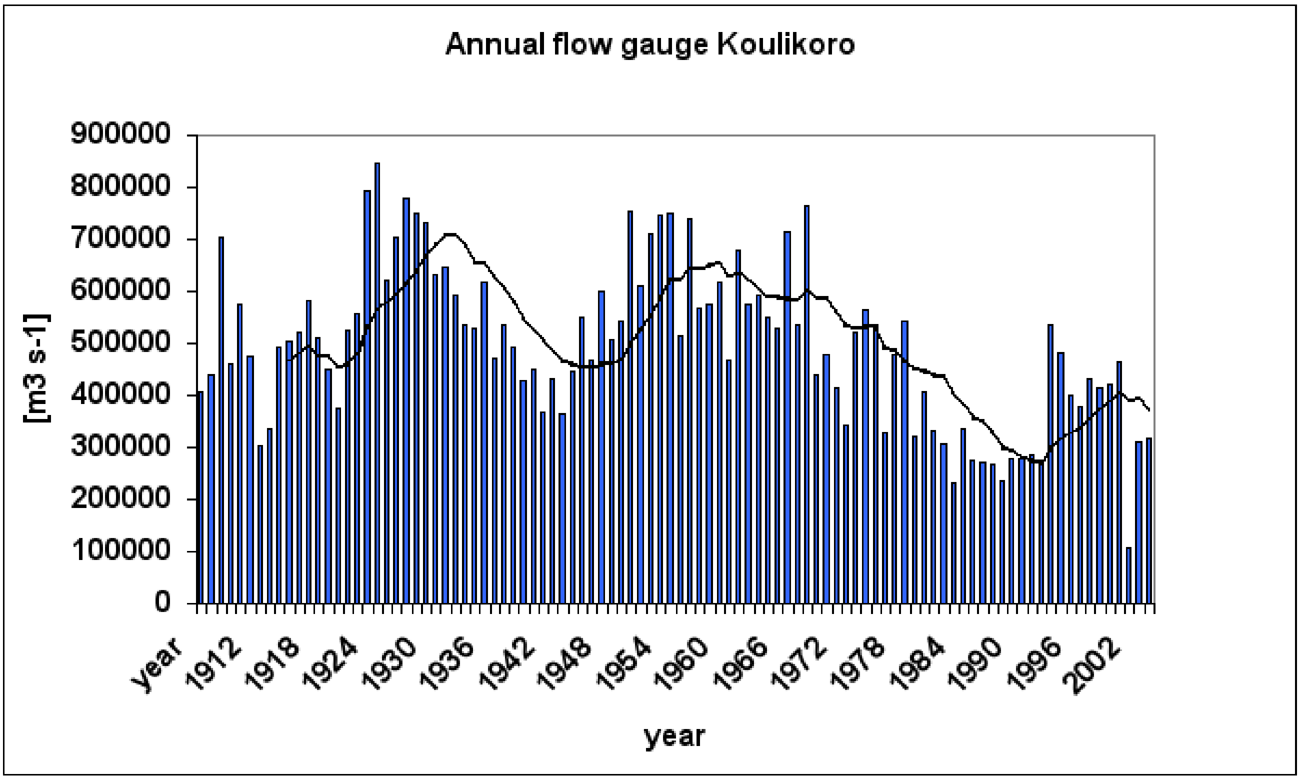


Figure 2.23. *Precipitation, Observations and Projections; Data Source: Österle & Böhm (2009); Hirabayashi et al. (2008)*

Table 2.9. *Rainfall Trends in Different Periods (Mali)*

Period	**West Mali [mm/year]**	**Inner Niger Delta [mm/year]**
1958-1984	-19.6	-4
1984-1994	+58.2	+8.84
1994-2007	-48.6	+5.54
1958-2007	-8.61	-1.09



2.4.2.2 Uganda

Figure 2.24 and Figure 2.25 show observations and projections of temperature and precipitation for two different sites in Uganda. The Nabajuzzi wetland is located near the city of Masaka and the Namatala wetland close to the city of Mbale. The illustrated data correspond to the 0.5° grid cells where the cities are located in.

Both sites are characterized by increasing temperature during the observation period. The variance of annual mean temperature is almost similar in both sites but slightly higher in the Masaka region than in the Mbale area. Regarding the trend obtained from linear regression over the observation period, the Nabajuzzi wetland area experienced an increase of approximately 0.018°C/year and the Namatala wetland region an increase of 0.014°C/year. These linear trends result in an increase of 0.9°C for the Nabajuzzi wetland area and an increase of 0.7°C for the Namatala wetland area during 50 years. According to the projected trends shown in Figure 2.18 and Figure 2.20, this might be a conservative assessment and temperature is more likely to increase faster in the future.

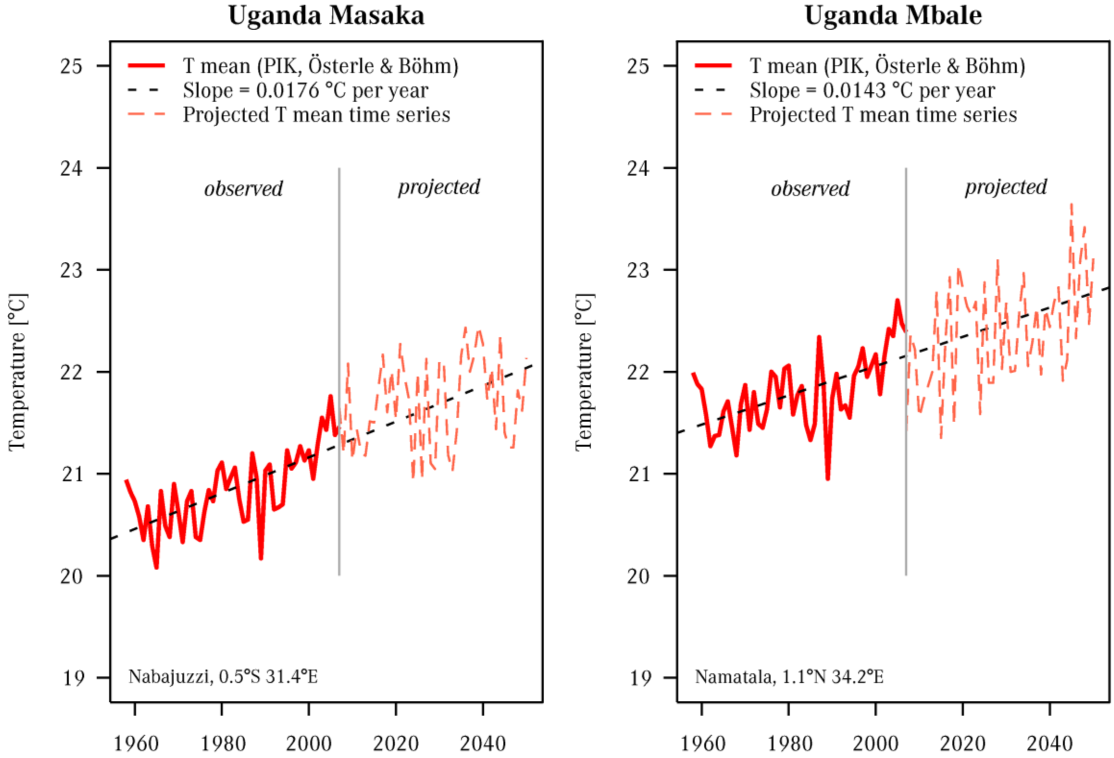


Figure 2.24. *Temperature, Observations and Projections, Data Source: Österle & Böhm (2009)*

The rainfall trends and patterns during the observation period are different in the two sites in Uganda. Rainfall variability was much higher in the Namatala wetland than in the Nabajuzzi wetland area. The Nabajuzzi area experienced increasing rainfall indicated by both datasets (0.227 mm/year, PIK) and (0.376 mm/year, H08). For the Namatala wetland area the datasets show opposing trends (-2.32 mm/year, PIK) and (+0.12 mm/year, H08). These trends were estimated by linear regression over the entire observation period. Dividing the observation periods into sub-periods shows the non-linear behavior of rainfall. It also emphasizes the limitations of projecting rainfall data into the future based on historical data. What is worth noting is that the precipitation trends during sub-periods are very different in both sites. The most obvious difference is that in the period between 1958 and 1993 the precipitation trend in Mbale showed a significant negative trend, whereas in Masaka one would visually divide this long period probably into three periods (with decreasing trends between 1958 and 1971, increasing trends between 1971 and 1986, and again decreasing trends between 1986 and 1992). From 1993 to 2007 precipitation increased significantly in Mbale, whereas the trend in Masaka was slightly negative.

According to this nonlinearity of precipitation, future rainfall patterns and trends are very uncertain. In order to capture a reasonable range of uncertainties, the projection periods were estimated on the basis of the linear trend derived from the observation period and extended with exactly the opposite trend. Thus, the projections show no trend at all but a possible range of future rainfall events. According to Figure 2.19 and Figure 2.20, precipitation is more likely to increase in Eastern Africa (Uganda). But these trends do not account for local effects.

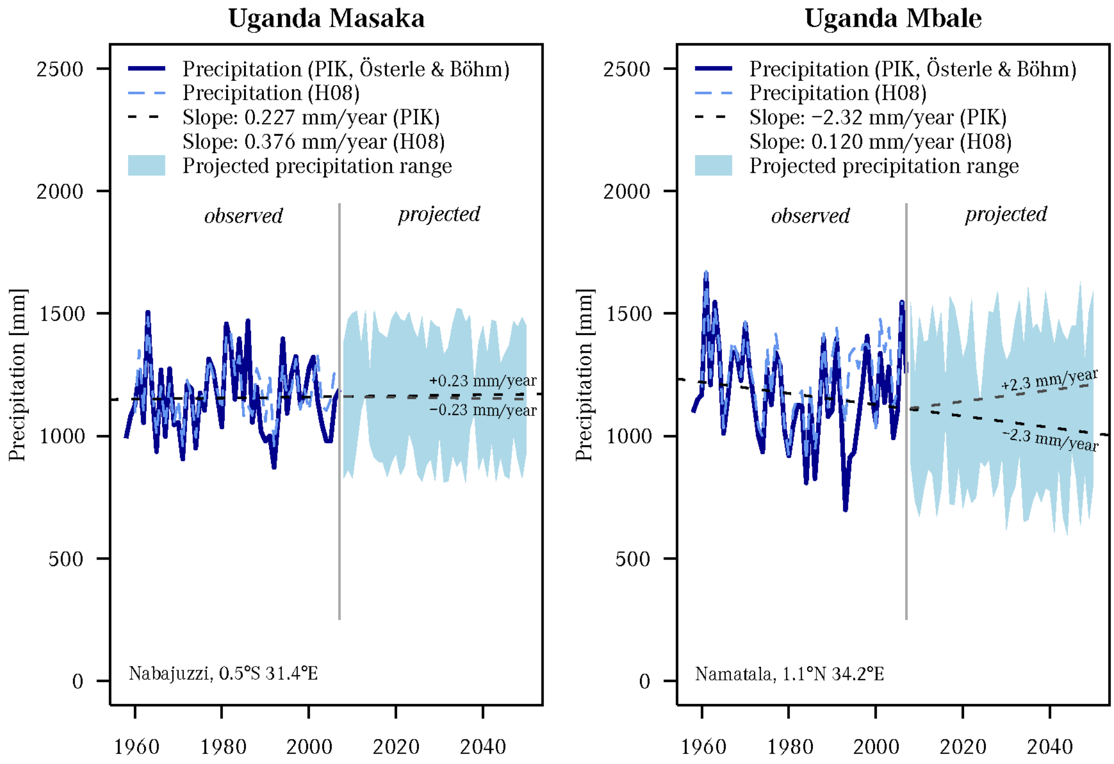


Figure 2.25. *Precipitation, Observations and Projections; Data Source: Österle & Böhm (2009); Hirabayashi et al. (2008)*

2.4.2.3 South Africa

The Ga-Mampa site is a riverine wetland of the Mohlapitse river which is a tributary to the Olifants river. Temperature and precipitation data shown in Figure 2.26 refer to the 0.5° grid cell where the wetland is located in. The headwaters of Mohlapitse are situated in the same grid cell.

The linear trend of temperature during the entire observation period is more or less equal to zero (indicating no trend). A visual assessment of annual mean temperature roughly shows that temperature was declining between 1958 and 1981 and increasing between 1981 and 2007. The negative linear trend in the first period is -0.037°C/year (corresponding to -1.8°C in 50 years) and the positive trend in the following period is 0.012°C/year (corresponding to +0.61°C in 50 years). According to the linear trend of the entire observation period, projected temperature is very slightly decreasing with a very slow pace of -0.05°C in 50 years. Hence, projected temperature data in Figure 2.26 show no obvious trend. This assumption is not in line with the trends suggested by Figure 2.18 and Figure 2.20, where significant increasing temperature trends are projected.

The annual mean rainfall during the observation period was within the range of 380 and 1370 mm, indicating very high annual variability. Linear regression over this period shows a decreasing trend of -1.27 mm/year (Österle & Böhm, 2009). Looking at the precipitation graph in Figure 2.26 shows again that rainfall does not follow a linear trend but is rather characterized by nonlinearity. Thus, in order to project annual precipitation amounts we cannot simply expand the observed trend into future. More sophisticated approaches, such as regional downscaling of GCM projections are required to achieve this. But for a rough assessment an opposing trend of +0.5 mm/year was included in order to illustrate possible future rainfall ranges. Regarding the precipitation trend shown in Figure 2.19 it is more likely that rainfall will decrease in South Africa up to mid-century. This is line with the projections for the end of the 21st century, as illustrated in Figure 2.20.

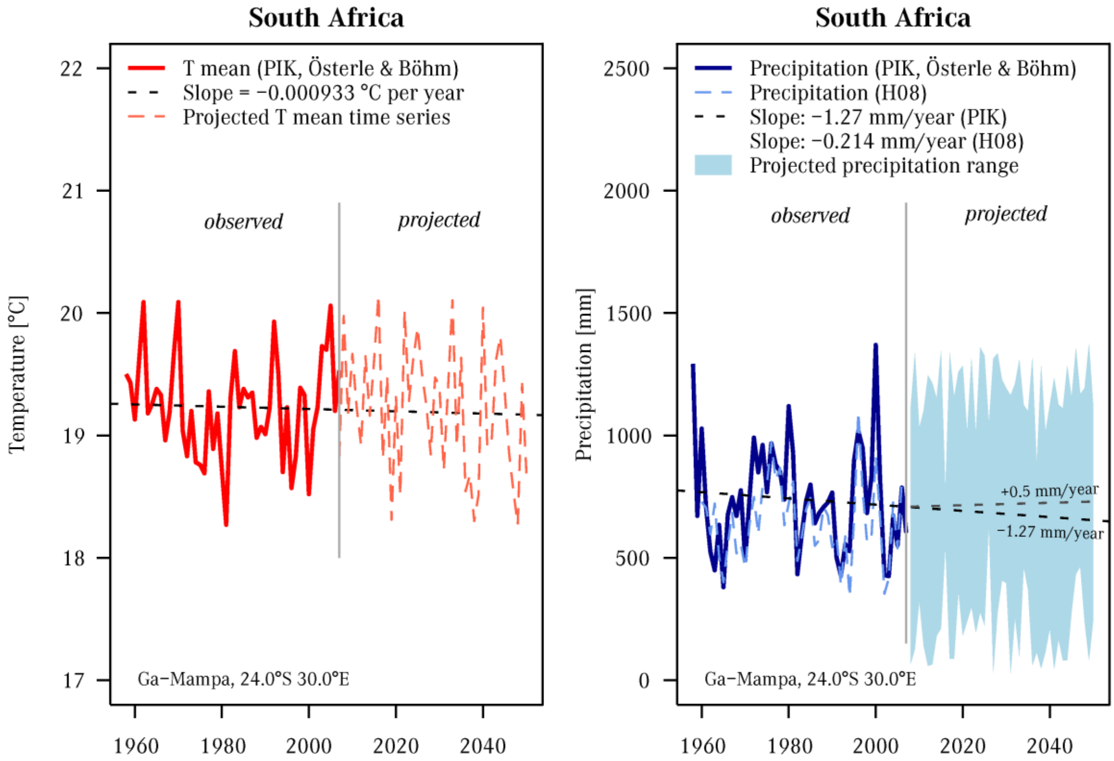


Figure 2.26. *Temperature and Precipitation, Observations and Projections; Data Source: Österle & Böhm (2009); Hirabayashi et al. (2008)*

2.4.2.4 Ecuador

In contrast to the African case studies, temperature and precipitation data are only available from Hirabayashi et al. (2008). Therefore, temperature data are not representing mean air temperature but average minimum and maximum. Although the H08 dataset provides daily values from 1948 to 2006 we downloaded and analyzed temperature data from 1970 to 2006 and precipitation data from 1960 to 2006 so far. The data are visualized in Figure 2.27. They correspond to the grid cell where the Abras de Mantequilla wetland and its headwaters are located in. The Abras de Mantequilla river is a tributary to river Vinces.

Annual average maximum and minimum temperatures show an increasing trend of approximately 0.024°C/year and 0.02°C during the observation period. This corresponds to an increase of 1.2°C for maximum and 1.1°C for minimum temperatures during 50 years, respectively.

Mean annual precipitation during the observation period shows a very high variability ranging between 874 and 2322 mm/year. As discussed in the previous sub-sections, it is not reasonable to project precipitation data into future based on linear regression of historical data. Although a positive linear trend of +1.74 mm/year (87 mm / 50 years) was estimated on the basis of observed data between 1960 and 2006, future rainfall patterns are highly uncertain. However, the estimated positive trend is in line with the assumed increasing trends shown in Figure 2.19 and Figure 2.21. Furthermore, investigation of seasonal shifts of observed and projected rainfall must be accomplished.

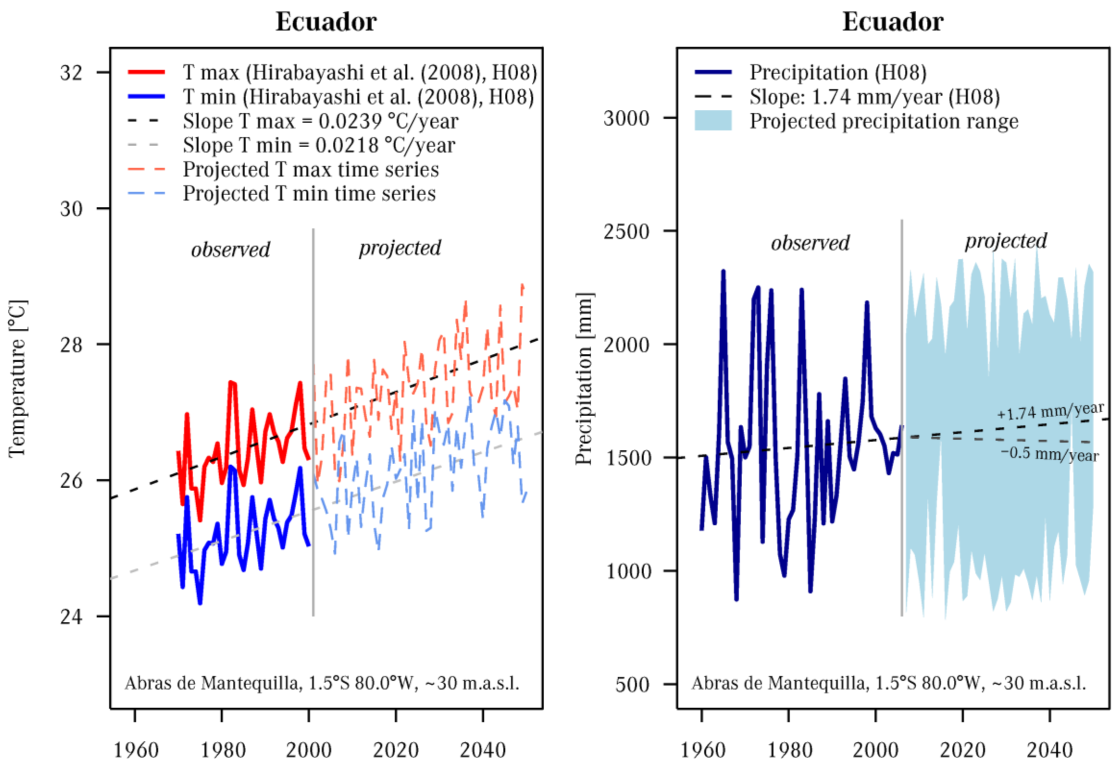


Figure 2.27. *Temperature and Precipitation, Observations and Projections; Data Source: Hirabayashi et al. (2008)*

2.5 Conclusions

The purpose of this report on global change scenarios was to illustrate three possible future global pathways, their potential implications for the southern WETwin case studies, and to determine boundary conditions for the development of regional scenarios. The report showed projections for some variables/indicators at different spatial levels. Further downscaling of all data from the SRES region and country level to the regional/local level is required. The regional/local level in this context comprises the wetland area including the upstream part of the corresponding river basin. More indicators need to be included and local knowledge is required to develop reasonable regional scenarios.

The focus of this report was mainly on socio-economy. Climate projections have been included to draw a more complete picture of possible futures. The current state of climate projections should be considered as preliminary, more sophisticated approaches are required to develop reasonable regional climate scenarios. This will be achieved later in the WETwin project.

2.5.1 Population

As shown in Figure 2.10 to Figure 2.13, population is projected to increase in all scenarios in Mali, Uganda, and Ecuador up to mid-century. In South Africa the projections for A2 (R-Ec) show also increasing trends, but the assumption made by three data sources for the A1B (G-Ec) and B1 (G-Env) scenarios differ. Where Van Vuuren et al. (2007) project population increase up to 2030 and a decline thereafter, IIASA (2007) and CIESIN (2002) assume a decreasing trend starting already in 2010.

Local population development is important to assess the future pressure of humans on the environment (water demands, waste water treatment, food production etc.).

What are the local trends in the case study areas for population development under different boundary conditions? What conditions could lead to decreasing population growth rates?

2.5.2 GDP

Increasing GDP per capita is projected for all scenarios and all case study countries (see Figure 2.14 to Figure 2.17). The highest growth rates are projected for South Africa and Ecuador. The A2 (R-Ec) scenario projects the lowest GDP per capita growth rates for all case study countries.

GDP might be used as an indicator for life expectancy (Alberini et al., 2006), adaptive capacity, inequality etc. The value of GDP as such an indicator is often criticized in scientific literature, hence further discussion is required on reasonable and applicable indicators, particularly for adaptive capacity. However, economic growth is a dominant driver of energy demand (Van Vuuren & O'Neill, 2006).

2.5.3 Energy Consumption

Projection data of energy consumption at the country and local level are still lacking. Figure 2.8 to Figure 2.9 show only projections of energy consumption at the level of SRES regions. However, they indicate increasing per capita consumption for developing countries for all scenarios, where the highest consumption growth rates are projected for the A1B (G-Ec) scenario, and the lowest growth rates for A2 (R-Ec) scenario.

Per capita energy consumption could be used as an indicator for living standards, resource use efficiency, etc.

2.5.4 Land Use

Regional land use projections assuming different boundary conditions are still lacking. Figure 2.2 to Figure 2.4 indicate some trends only at the SRES region scale. We must figure out how the pressures on land use could be differentiated in the three scenarios. Main pressures are population growth and climate change but also economic development. Expected impacts are changing demands of natural resources and efficiency of resources use. Technological progress might mitigate certain environmental problems but will be introduced at a different pace and intensity in the different scenarios. New technologies could have an impact on current agricultural management practices. What are possible impacts of globalization / regionalization on food production, biomass energy production, alternative land uses, and forests?

2.5.5 Climate

As mentioned previously, the illustrated climate projections were obtained by using a rather simple method. An analysis of annual means, as has been done in section 2.4, easily leads to wrong conclusions. Hence, there is a need to investigate seasonality of climate change and climate variability. More sophisticated methods of regional downscaling will be applied later in the project.

3 DPSIR

3.1 Introduction

The primary objective of this chapter is to identify and explore the major environmental and livelihood problems (impacts) at the study sites, with special regard to those problems that are going to be dealt with within the WETwin project. Exploring the problems involves the identification of Driving forces and Pressures, as well as those components of the system's State, which have been modified by the Driving forces and Pressures thus causing Impacts (the problems). The chapter also aims at reviewing potential measures (Responses) proposed by various stakeholders and researchers, for mitigating the problems.

Relationships between Driving forces, Pressures, State, Impact and Responses (DPSIR) have been analysed with the help of the DPSIR approach (Becker, 2005; Soncini-Sessa 2005). DPSIR supports the establishment of cause-effect relationships behind a given problem, and helps in screening measures with which the problem can be solved.

The ultimate objective of DPSIR analyses is to identify the impacts on Ecosystem Services of the wetlands. Accordingly DPSIR analyses are preceded by identification of relevant Ecosystem Services in this document. Classification of Ecosystem Services is carried out according to the system given in the Millennium Ecosystem Assessment (Finlayson et al., 2005).

Exploring cause-effect relationships contributes to Task 3.3: 'Qualitative description of natural status, drivers, pressures and functions', while screening measures supports Task 7.4: 'Identification of generic measures for improving wetland management' of the WETwin project (WETwin, 2008). The temporal dimensions of components of the DPSIR chains will also be analysed. It will be specified whether a given driving force, pressure, state or impact characterises the present state or (/and) will emerge in the future. This later means that local scale projections were implemented within the frame of the DPSIR analysis too. It is important to state that at the prediction of future states of the various DPSI elements, it was assumed that the envisaged management options (responses) are not implemented.

Based on the DPSI analyses, tradeoffs between ecosystem services have also been identified and presented in this report.

3.2 The Driving Forces – Pressures – States – Impacts - Responses (DPSIR) Scheme – a "Control Paradigm"

The evolution of a natural system subject to anthropogenic pressure is generally described by the Driving forces – Pressures – States – Impacts - Responses (DPSIR) scheme (Figure 3.1), as suggested by the European Environment Agency (EEA), cf. OECD (1994), UNCSD (1996). The Driving forces generate a Pressure upon the system, thus altering its State. This alteration represents an Impact, i.e., an effect upon the environment and society (Becker, 2005). When the society is affected in an unfavourable way, it reacts by devising and implementing Responses that can target either the Drivers, the Pressures, the State, or directly the undesired or threatening Impacts, so that they are avoided, reduced, or compensated (Becker, 2005). This is represented in a simplified way in the DPSIR scheme.

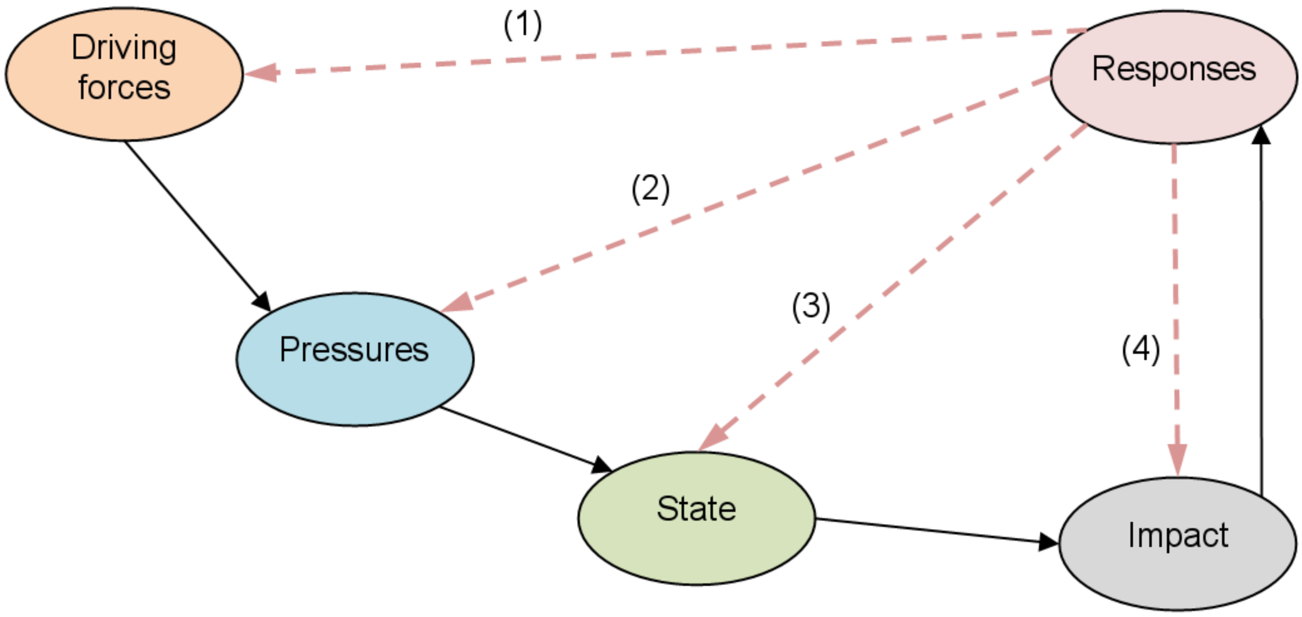


Figure 3.1. *Basic form of the DPSIR framework (after Becker, 2005)*

For the WETwin project elements of DPSIR are defined in the following way:

- **Driving forces** are represented by natural and social processes which are the underlying causes and origins of *pressures* on the environment (Fondazione Eni Enrico Mattei, 2006).
- **Pressures** are outcomes of the driving forces, which influence the current/future environmental *state* (Fondazione Eni Enrico Mattei, 2006).
- **State** describes physical, chemical or biological phenomena in the given reference area. It reflects the condition of the environment (Fondazione Eni Enrico Mattei, 2006). E.g. air, water, soil quality. Pressures cause **Changes of State** (e.g. decreased water levels, eutrophication) which ultimately result in *impacts*.
- **Impacts** on population, economy, ecosystems describe the ultimate effects of *changes of state*, in terms of damage (or benefit) caused to Ecosystem Services. E.g. biodiversity loss, reduced flood regulation capacity.
- **Responses** demonstrate the efforts of society (e.g. politicians, decision-makers) to solve the problems encountered in the investigated system (Fondazione Eni Enrico Mattei, 2006). E.g. policy measures.

3.3 DPSIR Analysis at the WETwin Study Sites

The DPSIR chains as well as an analysis of ecosystems services of the WETwin case studies are reported in D 3.2 (Zsuffa et al., 2010).

3.4 Analysis of Most Important Drivers and Pressures

An overview of the most important drivers and pressures as indicated by all case studies shows Table 3.1 below.

3.4.1 Climate change/variability

Climate change/variability is not yet addressed in the DPSIR chains by the following sites: Abras de Mantequilla, Ga Mampa, Gemenc, and Lobau.

Concluding discussions within the WETwin consortium on this topic following statements were given:

- Impact of climate change on the Gemenc is being investigated. There can be two kinds of impact:
  - Increasing temperature increases evapotranspiration from the wetland water bodies, which may enhance the desiccation problem.
  - Climate change changes the water regime of the Danube which will have impact on the floodplain
  - For the time being climate change and its consequences are not considered as considerable threats to the Gemenc.
- Including climate change impacts in the Lobau case study is currently being investigated.
- Climate change and variability are important drivers in the GaMampa case study and will be included in future DPSIR chains and vulnerability assessment.
- According to a report by Cedeño and Cornejo-Grunauer (2010) there are implications of climate change on the water regime in the study area (Abras de Mantequilla, Ecuador). Thus, climate change will be considered as a driver in future DPSIR chains.

3.4.2 Drivers and Pressures of the social domain

Attributes of the social domain seem to be mainly an issue in the Southern sites.

3.4.3 Energy production

Energy production was only addressed by the European sites Gemenc (Hungary) and Spreewald (Germany). Concluding discussions within the WETwin consortium on this topic following changes are suggested:

Including hydropower production (existing/planned) in the upstream catchment as a driver in the following case studies:

- Inner Niger Delta (Mali)

- Abras de Mantequilla (Ecuador)
- Lobau (Austria)

Energy production is a driver in the Spreewald case study as well. In contrast to the other study sites it is energy production related to open pit coal mining, not hydropower.

3.4.4 Agriculture

In the current state there is not yet a consistent view on agriculture, whether it is a pressure or driver or even a state in the DPSIR chain. Therefore, a first rough distinction of agricultural activities into *subsistence farming* and *cash crops* has been proposed.

1. Agriculture for food production mainly *subsistence farming* (consumed within the region in order to feed local people)
2. Agriculture as an economic dimension, *cash crops* (to produce goods for trade, be it food or non-food products)

Of course, both agricultural sectors can be addressed by one case study. In the first case, agriculture (food production) is an attribute of the social domain and in the latter an attribute of the economical domain.

As a preliminary result, based on discussions, it can be stated that it makes sense to divide agricultural activities into different categories. For economic modelling (in terms of farming practices, production function estimation and assumptions taken to characterize the economic behaviour of farmers) the treatment given to each type of agricultural activity is completely different.

Consideration of agriculture being a driver or pressure might also be related to the scale (agriculture at the river basin or in the wetland, for instance).

Four Southern sites (IND, AdM, Ga Mampa, and Namatala) indicate a link between "Population growth" and "food production" or "increasing cropping/agricultural encroachment", respectively. Where "Population growth" is always a driver, "food production" is sometimes considered as a driver and sometimes as a pressure. Depending on the perspective, both assumptions might be reasonable.

Another interesting difference between the Southern and European sites is that agriculture is considered to be a Pressure in the southern sites, but a Driver in the European sites.

Table 3.1. *Matrix of Most Important Drivers and Pressures*

		Natural/Environmental					Social						Institutional		Economical/technical/land use							
		Climate change	Climate variability	Water quality	Erosion	Sedimentation	Population growth	Urbanization	Food production / need for food	Education / Env. awareness	Recreation	Health / Sanitation	Environmental mgt.	Financial issues	Agriculture	Forestry	Fishery	Energy production	River regulation	Navigation	Flood control	Water intake/abstraction
Southern Sites	Inner Niger Delta	[Driver]		[Pressure] 12)		[Pressure] 34)	[Driver]		[Driver] 2)	[Driver]		[Driver] 5)	[Pressure] 15)	[Driver]				[Driver] 33)	[Driver]			[Driver] 6)
	Nabajjuzzi	[Pressure]	[Driver]	?			[Driver]	[Driver]				?										[Pressure] 7)
	Namatala	[Driver]	[Driver]				[Driver]								[Driver] 4) [Pressure] 25)							
	Abras de Mantequilla	?	?	[Pressure] 8)			[Driver]	[Driver]					[Pressure] 17)		[Pressure] 25)		[Pressure]	[Driver] 33)	[Driver] 24)			
	Ga Mampa	?	?		[Pressure]		[Driver]			[Driver] 19)			[Driver] 20) 21) 22)	[Driver] 18) 22)	[Pressure] 23)							
European Sites	Gemenc	?	?		[Pressure] 36)	[Pressure] 34) 35)							[Driver] 16)			[Driver] 14)		[Driver] 33)	[Driver]	[Driver]	[Driver]	
	Lobau	?	?	[Driver] 11)	[Pressure] 36)	[Pressure] 35)		[Driver] 1)			[Driver] 28)				[Driver] 3)			[Driver] 33)	[Driver]	[Driver]	[Driver]	
	Spreewald	[Driver]											[Pressure] 31) 32)		[Driver]			[Driver] 29)				[Pressure] 30)

Driver
Pressure

Table 3.2. *Legend of Table 3.1*

1) urban development
2) increasing need for food
3) intensive agriculture
4) agricultural activities risky and less productive
5) lack of sanitation / sanitary dispoal and water use
6) increasing intake from the Niger upstream of IND
7) increasing intake
8) agrochemicals in surface waters
9)
10)
11) high nutrient loads
12) untreated domestic waste water into water bodies
13)
14) Wood production (floodplain)
15) Lack of coordination
16) Dual mgt of Forestry/National park
17) poor solid waste mgt
18) Poverty
19) lack of / poor knowledge about wetland functioning
20) Poor mgt of irrigation scheme
21) lack of control of wetland use
22) reduced government support to irrigation agriculture
23) increased cropping and grazing in the wetland
24) multipurpose dam and water transfer projects upstream
25) agricultural encroachment
26)
27) channelized river bed
28) increasing number of visitors
29) Energy production (coal) in the upstream catchment
30) decreasing water inflow; wetland must provide min. outflow
    + lowering the groundwater table
31) Melioration
32) open-pit mining
33) hydropower production (existing/planned) in the upstream catchment
34) sedimentation in the lateral canals
35) aggradation of the floodplain surface
36) river bed incision

4 Storylines

4.1 The Aim of Storylines

An important basis to accomplish the vulnerability assessment is to formulate well defined and specific research questions (storylines) for each case study area. It should be emphasized here that a general comparison of the vulnerability between different regions (case studies) is difficult, impossible, or at least scientifically not sound. This is particularly true if different attributes are affected by a hazard/pressure. Hence, an assumption like “The Nabajjuzi wetland is more vulnerable to climate change than the GaMampa wetland” is, due to different boundary conditions, different attributes affected etc. too general and thus not correct. In order to build a sound basis for the vulnerability assessment and for a possible comparison between case studies, it is necessary to develop specific storylines for each case study. To what degree a general comparison of vulnerability will be allowed and what methods and indicators will be applied in order to achieve this will be decided at a later stage of the project.

The required storylines are to a large degree in line with the DPSIR framework. They can be considered more or less as a concrete and disaggregated formulation of the DPSIR chain(s).

Based on these storylines global change scenarios (IPCC, 2007) will be downscaled to the case study areas in order to assess the vulnerability to different boundary conditions (climate change, socio-economic, agricultural, and industrial development).

After Füssel (2007) it is fundamental to use four dimensions to describe a vulnerable situation. These dimensions are:

1. **System**: The system of analysis (coupled human-environment system, population group, economic sector, geographical region ...)
2. **Attribute(s) of concern**: The valued attribute(s) of the vulnerable system threatened by exposure to a hazard (human lives, income and cultural identity of a community, biodiversity, agricultural productivity ...)
3. **Hazard** (pressure, stressors): A potentially damaging influence on the system of analysis. A physical event or phenomenon or human activity that may cause: Loss of life or injury, property damage, environmental degradation ...
4. **Temporal reference**: The point in time or time period of interest (current situation, short-term assessment, long-term assessment)

The general nomenclature of the storyline that allows to fully describe a vulnerable situation is: vulnerability of a system's attribute(s) of concern to a hazard (in temporal reference) (Füssel, 2007).

4.2 Example

The following sentence would be an example for a not well defined problem:

Example 1: “*Assessment of the vulnerability of the GaMampa wetland to climate change*”.

The GaMampa wetland represents the dimension *system* in this example. The dimension *hazard* is climate change. Missing elements are the dimensions *attributes of concern* and *temporal reference*. Thus, it needs to be specified what or who is endangered by or is suffering from a “potential” hazard/pressure and what the time period of interest is.

In example 2 “human population's livelihood” in general and “access to water” in particular were added to specify the attributes of concern. “The next 30 years” indicates the temporal reference. Moreover, we think that it is feasible to include more than one hazard to the storyline, if they have an impact on the same attribute(s) of concern. Otherwise, another storyline should be formulated. Climate change as a hazard might be considered as too imprecise and could be further specified by replacing climate change with “temperature increase/decrease or rainfall increase/decrease”.

Example 2: “*The vulnerability of the human population's livelihood (access to water) in the GaMampa wetland to climate change and population growth over the next 30 years.*”

4.3 Storylines of the Malian Case Study

On the basis of the DPSIR-chain analysis (Zsuffa et al., 2010) it can be concluded that changes in the hydro-morphological regime of the Niger River has large implications for the social-ecological system of the Inner Niger Delta. Hence, the storylines are focussing on an analysis of the **vulnerability of the IND to changed hydro-morphological regimes, including population growth and climate change and variability**. The two main issues in the Inner Niger Delta are the availability of water in dry season and the malaria problem which is partly due to growth of Anopheles the irrigated rice fields in Office du Niger. Both problems are strongly dependent on hydrology and water allocation in the catchment. A measure to control the flow regime is the management of the existing dams Sélingué and Markala. The Selingué dam is used for water storage, flow control, irrigation and hydropower. The Markala dam is operated by Office du Niger and its main purpose is water provision for irrigation. Zwarts et al. (2005) analyzed the impact of dams on the flow regime in the Upper Niger Basin. According to the authors both dams lead to a reduction of peak flow during the wet season. The influence of the dams during the dry season is different. In order to ensure energy production the outflow from the Sélingué reservoir in the dry period is usually higher than the natural flow. Hence, past dam management at the Sélingué dam had a positive effect during the dry season. In contrast, the Markala dam is used for irrigation purposes abstracting up to half of the river water in the dry period. In addition, rice farming in Office du Niger leads to an increased Malaria problem. Other threads for the human-ecological system of the IND are the obvious impacts related to the planned Fomi dam in Guinea. This reservoir is meant for hydropower in combination with irrigation and flood control (Zwarts et al., 2005). We assume that dam management can be optimized to the following objectives:

- Irrigation (increased water abstraction from the river/reservoirs)
- Energy production (maximized storage filling during wet season)
- Guaranteed minimal low flow during dry seasons into the IND

Based on these dam management options, the following research questions will be tackled:

Assessment of the impact of different dam management options on

- vector- and water-borne diseases
- ecological functions/services of the key habitats (waterbirds, fish species as biol. indicators) in the Inner Delta
- nutrient retention and water purification functions/services of the wetland (nutrient removal by sediment retention, biol. purification)

Table 4.1 summarizes the corresponding impact assessment and research questions. Global change scenarios, including climate change and variability as well as population growth, will be applied to these research questions in order to assess the impact of different dam management options under changing external conditions. A variety of scenario combinations is used in order to capture uncertainties related to unpredictability of the future.

Table 4.1. *Impact Assessment (Mali)*

Impact assessment	of	on
	dam management optimized **towards irrigation purposes**	the spreading of vector- and water-borne diseases in the IND.
		ecological functions/services of the key habitats (waterbirds, fish species as biol. indicators)
		nutrient retention and water purification functions/services of the wetland (nutrient removal by sediment retention, biol. purification)
	dam management optimized **towards energy production**	the spreading of vector- and water-borne diseases in the IND.
		ecological functions/services of the key habitats (waterbirds, fish species as biol. indicators)
		nutrient retention and water purification functions/services of the wetland (nutrient removal by sediment retention, biol. purification)
	dam management optimized **towards guaranteed minimal flows to the IND**	the spreading of vector- and water-borne diseases in the IND
		ecological functions/services of the key habitats (waterbirds, fish species as biol. indicators)
		ecological functions/services of the key habitats (waterbirds, fish species as biol. indicators)
	Optimized for maximizing the flooded areas during the wet season	the spreading of vector- and water-borne diseases in the IND
		ecological functions/services of the key habitats (waterbirds, fish species as biol. indicators)
		ecological functions/services of the

key habitats (waterbirds, fish species as biol. indicators)

These four management options are investigated in the qualitative and quantitative assessment at the river basin scale. In MCA additional options focusing on water quality improvement and water supply are investigated at the wetland scale. Bakary: 50m3/s threshold for minimum flows, but OdN wants to deliver only 40m3/s.

According to the framework of Füssel (2007), explained in section 4.1, the *system of analysis* is the social-ecological system of the Inner Niger Delta. The *attributes of concern* are listed in the third column of Table 4.1 and the *hazard/stressor* in the second column. Additional stressors in all assessments are climate change and population growth. The *temporal reference* is the period of 2010 to 2050. The storylines derived from the DPSIR chains (Zsuffa et al., 2010) and Table 4.1 are explained in the following.

4.3.1 Storyline 1

Assessment of the vulnerability of the social-ecological system of the Inner Niger Delta to spreading of vector- and water-borne diseases due to different dam management operations under climate change and population growth in the period from 2010 to 2050.

Diseases such as malaria, schistosomiasis, and semi-epidemic diarrhoea are strongly related to the omnipresence of shallow stagnant water and the deplorable sanitary conditions. It is expected that a further expansion of irrigation zones will bring along a further spreading of these diseases (Zwarts et al., 2005). In order to assess the impact of different dam management objectives on the spreading of water- and vector-borne diseases, modelling of flood extents, water levels, and spatial structures and distances of ponds is required. An important prerequisite in this connection is the availability of a detailed terrain model.

4.3.2 Storyline 2

Assessment of the vulnerability of ecosystem functions and services of key habitats in the Inner Niger Delta to different dam management operations under climate change and population growth in the period from 2010 to 2050.

Key habitats in this context are flood forests, bourgou fields (Echinochloa stagnina: Burgu Millet, hippo grass which is important for livestock), breeding ground for fish and fish eating waterbirds, and areas to cultivate floating rice. This storyline addresses several ecosystem services with impacts on many income sectors such as fishery, agriculture, and livestock. Ecosystem services are considered to be mainly impacted by different inflow rates to the inner delta.

4.3.3 Storyline 3

Assessment of the vulnerability of water purification functions and nutrient retention in the Inner Niger Delta to different dam management operations under climate change and population growth in the period from 2010 to 2050.

Water purification and nutrient retention functions in a wetland are determined by various physicochemical and biological parameters, such as flow velocity, turbulence, travel distance, vegetation etc. Main input to the impact assessment are different inflow scenarios according to the different management options, climate change and variability as well as population growth. These inflow scenarios are then the basis to model the wetland's retention capacity assuming different nutrient inputs.

4.3.4 Storyline 4 (under consideration)

Under consideration is a storyline related to water quality issues and drinking water supply in the Inner Niger Delta. Solid waste disposal and discharge of untreated waste water is a threat for the human population and ecosystem of the IND. Management options considered in this regard are:

- Treatment of waste and waste water
    - Installing/restoring WWTPs in Mopti and other settlements
    - Individual treatment of waste water in form of soak pits or similar
    - Open drainage
    - Dump sites for solid waste
- Boreholes for safe drinking water

4.4 Storylines of the Ugandan Case Studies

4.4.1 Nabajjuzzi case study

Nabajjuzzi wetland is a Ramsar site and in largely natural state. Therefore, wetland conservation should be in the focus. The main issues to be addressed are water quantity and water quality, both of which are important for livelihood services as well as for ecology.

As Uganda's population is rapidly growing and changes in the precipitation pattern due to climate change can be expected, there is the danger of drinking water shortage in Masaka municipality. Therefore, an important issue is the investigation of water availability at and downstream of Masaka for different population and climate scenarios.

To overcome water shortage, an additional intake point in Nakaiba arm approximately 10 km downstream of Masaka's wastewater discharge point has been suggested. Therefore, another important issue is the investigation of the water quality at this proposed water abstraction point.

Other problems like the obvious pollution by car washing and tank emptying, observation of river bank cultivation, erosion and the iron contamination could not be included due to limited time and resources.

Management options

- Keep the present intake point and abstract more water, if needed.
- New drinking water intake point in Nakaiba arm (quantitative measure). Possible sub-options are:
    - Install the new intake point and keep the present intake point. Abstract water from both sites.
    - Replace the present intake point by the new one.
    - Different locations of the new intake point are possible: in Nakaiba arm, at the outlet of Nakaiba arm, downstream of the point where Nakaiba arm joins Nabajjuzi's main arm.
- Additional measures to decrease the organic load in Nakaiba arm (qualitative, partly quantitative):
    - Papyrus harvesting in Nakaiba arm to reduce nutrients (it has to be investigated if this leads to a reduction of the organic pollution and bacteria).
    - Waste water treatment at Masaka to decrease the organic load by a central WWTP or individual treatment at houses.
- Ground water wells to obtain safe drinking water (qualitative).

Open questions

- Is the list of management options complete (for use in WetWin)?
- What is the current status in the discussion about the new intake point?
    - How is probability that this additional intake point will be implemented?
    - Is there already a time-plan for implementation?
    - Who decides about the implementation?
    - What is the precise location?
    - What are the estimated costs for building the new intake point?
    - What are the estimated costs for maintenance of the new intake point?
- Is a WWTP at Masaka feasible?
    - What are the estimated costs?
    - Are the relevant decision-makers interested in installing a WWTP?
- Is there ongoing papyrus harvesting in Nabajjuzzi?
    - What are the amounts of papyrus harvested?
    - What is the market prize of papyrus?
- Are ground water wells feasible?
    - What are the estimated costs?
    - Are the relevant decision-makers interested in installing ground water wells?

Overall research question

Is the envisaged new drinking water abstraction point in the Nakaiba arm (downstream of Masaka's wastewater discharge) feasible in terms of water quality?

4.4.1.1 Storyline 1

Assessment of the vulnerability of water provisioning by the Nabajjuzzi wetland to the Masaka supply area to climate change/variability and population growth in the period 2010 to 2050.

Due to the growing population and urbanization trends in the Masaka district, there is an increasing demand of drinking water. Currently, the population is provided with drinking water removed from the Nabajjuzzi wetland by an intake point upstream of the city. Increasing demands as well as climate variability are likely to overstress the capacity of this intake point in future. Therefore it is planned to install a new intake point. It should be emphasized here that community waste water is discharged into the Nakaiba arm (Nabajjuzzi wetland). The envisaged additional intake point is planned to be installed approximately ten kilometres downstream of the city or waste water discharge point, respectively. Hence, not only water quantity issues will be tackled here, but also water quality issues including an assessment of the wetlands capacity to remove discharged nutrients. Seasonality of climate, streamflow (particular low flow periods), and vegetation is of outmost importance in this context.

4.4.1.2 Storyline 2

Assessment of the vulnerability of the Nabajjuzzi ecosystem and its riparian population downstream of the city of Masaka to increased water abstraction, climate change/variability and population growth in the period 2010 to 2050.

In this storyline the impact of various water abstraction and waste water discharge scenarios (as a consequence of storyline 1) on downstream Nabajjuzzi ecosystems and riparian populations are investigated. Downstream in this connection means downstream of the envisaged additional intake point.

4.4.2 Namatala case study

In contrast to Nabajjuzzi, Namatala is a highly modified, artificial wetland. The original, natural papyrus cover has been largely removed by farmland, mainly rice-fields. Therefore land-use planning should be in the focus of investigations.

The wastewater of Mbale town is treated only in stabilisation ponds where the main process is sedimentation of solid substances. The wastewater is then discharged into the wetland. The management options have been chosen to investigate a partly wetland restoration, with the aims of improving water quality and restoring part of the natural wetland vegetation.

Management options

- Land-use change: introduce “purification wetlands” downstream of Mbale’s waste water discharge point. Different sizes of these restored wetlands can be investigated. Here, the trade-off between water purification and ecology on the one hand and food production and income for the population on the other hand is crucial. The options are:
- Keeping the present state (almost only farmland)
- Replacing 5% of the farmland by papyrus
- Replacing 10% of the farmland by papyrus

- Replacing 15% of the farmland by papyrus
- Each of these options can be run with different papyrus harvesting regimes, i.e. harvesting different amounts of papyrus per year.
- Wastewater treatment plant: extend the present stabilisation ponds by a full WWTP. Here the obvious trade-off is between ecology and water quality on the one hand and the high costs of a waste water treatment plant on the other side.

Open questions

- Is the list of management options complete (for use in WetWin)?
  - Are there options that should be added?
  - Are there options that should be removed?
- Implementation of the wetland restoration (purification wetlands):
  - What is the probability to be implemented?
  - Acceptance of the local population?
  - Acceptance of decision makers?
  - What are the estimated costs?
  - Income by papyrus harvesting: What is the market prize of papyrus?
- Is a WWTP at Mbale feasible?
  - What are the estimated costs?
  - Are the relevant decision-makers interested in installing a WWTP?

The Key research question

How do land practices, mainly rice growing, affect the wetland's water purification function? What is the effect of increased wastewater loads on rice production and water quality of the system?

The storylines

Assessment of the vulnerability of the wetland functions (water quantity & quality regulation) to increased wastewater loads, climate variability and rice production in the period 2010 to 2050.

We need to think about how best to bring in the issue of population growth since it affects both wastewater loads and encroachment for rice production.

4.5 Storylines of the South African Case Study

4.5.1 Storyline 1

Vulnerability of crop yields in GaMampa valley (irrigation scheme and wetland) to climate change over the next 20 (30) years

= what are the likely impacts of climate change on maize yields in the wetland and irrigation scheme in GaMampa

4.5.2 Storyline 2

Vulnerability of community livelihoods in GaMampa valley to climate change and population growth over the next 20 (30) years

= what will be the subsequent impacts on livelihoods of climate change and population growth?

4.5.3 Storyline 3

Vulnerability of wetland health (water supply, natural resources area) in GaMampa valley to climate change and population growth over the next 20 (30) years

= what will be the effects of climate change and land use change (due to population growth) in the next 20 years on wetland health (in terms of water supply and natural resources supply)

4.5.4 Storyline 4

Vulnerability of water supply in Olifants river basin to agricultural developments in wetlands, climate change and population growth over the next 30 (50) years

4.5.5 Management Options

4.5.5.1 Rehabilitate the Irrigation Schemes

This MO was identified as most relevant in tackling wetland invasion in the short term. It features 3 alternatives.

A.1a - LADC plan

This alternative aims at the set up of 100% commercial farming systems, through the introduction of a drip irrigation system with financial support from the state. It implies the destruction and abandonment of the existing gravity systems. The governance of irrigation infrastructure and agricultural production are in the hands of one legal entity as representative of all farmers of the Fertilis IS.

A.1b - Community oriented

This alternative aims at the continuity of wet season subsistence centered farming systems, through full renovation of the existing gravity irrigation infrastructure with financial support from the state. Such a system leaves opportunities for dry season cultivation of vegetables under the condition of a good management of the irrigation system. The governance is based on the community initiative, without support or incentives from the state. Management of the infrastructure is the responsibility of a community organization whereas agricultural production and marketing stays in the hands of independent production systems.

A.1c - Integrated alternative

This alternative aims at the intensification of farming system for commercial orientation, sustaining wet season maize production. Both irrigation infrastructures (drip and gravity) are coupled to provide flexibility to the system and allow dry season vegetable production. This will allow wet season maize farming without involving technical changes in the system, and dry season water efficient farming for commercial purposes.

Farmers who are interested in drip irrigation can invest in pipes to reach the reservoir and use low cost gravity drip irrigation systems using pressure from the altitude. It will guarantee that users have stakes in maintaining the drip infrastructure and other management responsibility. Governance of the gravity infrastructure is triggered by full responsibility of the community in canal rehabilitation. The governance of the agricultural production is left to the independent farming systems, and creation of a cooperative for marketing purposes may happen if needed.

4.5.5.2 Use Sustainable wetland farming practice

A.2 - Improved wetland agricultural practices

This MO proposes the adoption of a "package" to address weed control difficulties, potential fertility decrease, and guarantee biodiversity and soil conservation:

- The use of wetland adapted crops (rice, taro plants, and banana trees) to tackle the issue of drainage. These plants should be chosen as most wanted by the farmers for consumption purposes as to replace maize production. They should not be oriented towards commercial cropping to avoid the development of commercial farming opportunities in the wetland.
- The development of long term fallow periods, to tackle the issue of biodiversity, weed and pest pressure, as well as fertility. These fallow periods can be used for grazing and wild plant collection and thus should not be considered as unproductive. Local SHs believe that 3 consecutive years of no production should allow constitution of the original vegetation.
- The use of animal manure and vegetal inputs to sustain the MO content in the soil.
- The management of erosion through the use of crop residues for groundcover mulching.

4.5.5.3 Integrated and concerted land use planning

This MO refers to the set up of a land use planning process for wetland resources. It aims at instating at mid to long term vision on wetland resources use to guarantee their sustainability. There are 5 alternatives, concerning zoning and rotation practices.

- C.1a - 35% of wetland natural area, with rotation practices
- C.1b - 35% of wetland natural area , without rotation practices
- C.1c - 50% of wetland natural area, with rotation practices
- C.1d - 50% of wetland natural area , without rotation practices
- C.1e - 75% of wetland natural area, without rotation practices

Zoning refers to the delineation of areas in the wetland and identification of potential uses. This zoning should allow the midterm planning of human activities, instated by recognized bylaws. Its main purpose is to ease the conservation of wetland resources and avoid potential conflicts between users. Rotation practices refer to rotational use of the farmed wetland between cropping, grazing and natural vegetation.

These alternatives also include infrastructural consequences, including the use of living fences (bushes and trees) to ease their implementation.

4.5.5.4 Start tourism activities

Eco tourism refers to nature oriented outdoor activities which are not challenging for nature conservation. Cultural tourism makes use of specific local traditions to propose touristic activities. One possible alternative was identified:

- L.1 - Partnership with AIR for development of Eco tourism

It makes use of an existing semi governmental entity to provide financial and managerial support, the African Ivory Route (AIR), and municipal funds for renovation of an unused existing tourism infrastructure in GaMampa.

4.5.5.5 Prerequisites MOS

4 MOs are considered as prerequisites steps to implement A.2, C.1 and L.1 alternatives.

- L.3 - Road access and network coverage

The two alternatives were identified and grouped as necessary infrastructural management options. They imply that the South African government invests in road construction to Mapagane and in a public-private investment for installation of a phone network. The telecommunication network was identified as the most important infrastructure for future economic development and successful implementation of L.1 and A.1.

- G.1 Functioning Local resources management institutions

The governance issues in resource management were identified as a main stake for wetland sustainability. Three set of institutions were identified as relevant for future management of resources in the valley:

- Committee for livestock control (LCC) and rules
- Committee for Wetland resources management (WRMC)
- Traditional Council for Natural resources (TCNR)

These alternatives were proposed above are complex to set up and require further involvement of the research team for facilitation between potential SHs. It was decided to group them as a prerequisite MO, in order to simplify the MSs Analysis.

- G.2 Integrate wetland management plan to IDP

The implementation of any MO described above requires that a management plan is included in the municipal IDP. This is for the simple reason that it is necessary in order to receive government financial support in implementation of the MOs alternatives, through the municipality.

- G.3 Present / Implement legislation at local level

This MO refers to the introduction and enforcement of the South African legal framework at the local level, in order to enforce decisions and bylaws induced by the implementation of MO alternatives. One of the main local challenges on this topic is the identification of a DWA office to manage the Mohlapitsi river basin. The following MO was selected for further analysis of the MSs:

Source: List_of_MOs_GaMampa_10-11-2010.doc from Clément Murgue (10.11.2010)

4.6 Storyline of the Ecuadorian Case Study

Research questions

- How high is the water availability in the wetland area? Is it permanent or seasonal?
- Is water in acceptable quality levels for drinking, irrigation?
- What is the influence that a wetland and its adjacent river (sub) catchment have on each other?
- How to assess the adaptability of the wetland-river catchment system facing climate changes events?
- What are the most probable scenarios (m.i.w.) and best management strategies for the wetland and river catchments in study in a near future?

Assessment of the vulnerability of the AdM ecosystem (functions/services) to

5 Initial Vulnerability / Impact Assessment

According to Gallopín (2006) there is no consensus on the meaning of the vulnerability concept used in different research traditions. Therefore, we explain the concept of vulnerability and vulnerability assessment as it is used in our study in the following. Vulnerability is a property of a social-ecological system (Adger, 2006) and a function of the system's sensitivity, its adaptive capacity, and its exposure to stress or perturbation (McCarthy et al., 2001). Sensitivity and adaptive capacity are clearly attributes of the system, whereas exposure determines the relationship to a perturbation. The degree of the system's vulnerability highly depends on the properties of the perturbation to which the system is exposed or not exposed to. Moreover, we use the term "storyline" to describe a well-defined research question with regard to a vulnerable situation. According to Füssel (2007), at least four dimensions are required to meaningfully describe a vulnerable situation, the system of analysis, the attribute of concern, the hazard (perturbation), and the temporal reference. Hence, a storyline spans the entire vulnerability assessment process, as illustrated in Figure 5.1 below.

The vulnerability assessment performed in the case studies is a process including the following steps:

- Simulation of a baseline scenario to represent the current state with various models (eco-hydrological, hydraulic, habitat models).
- Definition of indicators and corresponding value ranges representing the space of desired state(s) of the system.
- Development and application of scenarios (climate change and socio-economic).
    - The system is exposed to perturbations (changing external conditions).
    - The system's sensitivity to perturbations is determined by the difference of the system's state(s) under scenarios conditions and the system's state of the baseline scenario (current state).
- Application of different management options.
    - Evaluation of the impact of management options.
    - Determination of adaptive capacity by comparison of scenario results with and without management.
- Assessment of the system's vulnerability, where the vulnerability is determined by the difference between the state of the system in each scenario (including management options) and the desired state.
- Vulnerability mapping

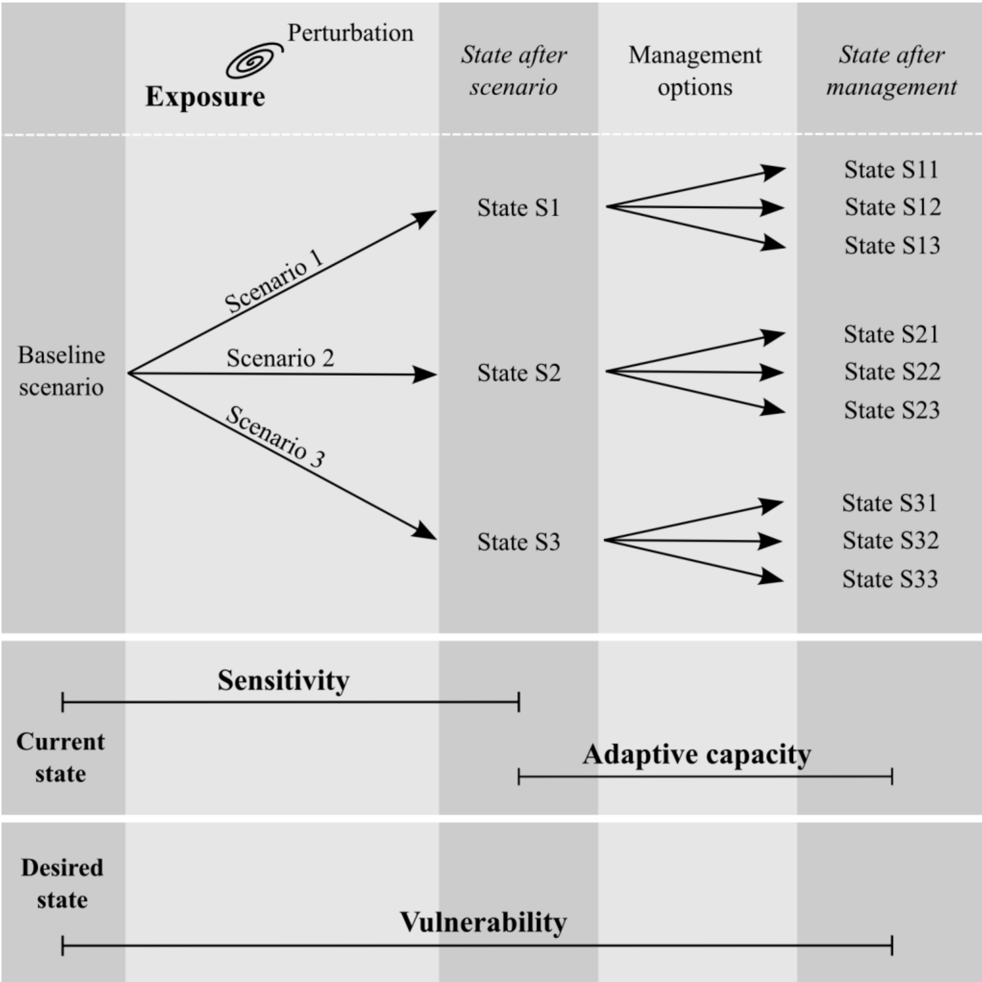


Figure 5.1. *Vulnerability assessment process*

Figure 5.1 illustrates the vulnerability assessment process highlighting the components of the vulnerability concept. Global change scenarios are applied to the baseline scenario in which the system is exposed to different perturbations. The reaction of the system to stress is the difference between the current state and the three scenario states (without management) and determines the system's sensitivity. In the next step, various management options are applied to the three scenarios. The system's adaptive capacity is then determined by comparing the system states with and without management options. The vulnerability of the system is finally the result of the impact of management options (adaptive capacity), the system's sensitivity to stress, and the exposure to different perturbations (global change scenarios). It will be assessed for each scenario and each management option by comparing the states of the system including management options and the desired state. The desired state is actually a certain space of possible system states confined by a range of defined indicator values. In the illustrated example we produce nine different vulnerability situations captured by a so called "storyline".

The definition of a system's vulnerability as being the difference between the system's state(s) after each scenario including adaptive measures (management options) and the desired state, has implications for the initial vulnerability assessment. Hence, in this report we perform an impact assessment of proposed management options rather than a "real" vulnerability assessment.

5.1 Mali

Mali is among the poorest countries in the World, with 65% of its land area desert or semi-desert (WWF, 2008). The Niger River plays an important role in Mali's economy providing water for irrigation, fish, drinking water etc. The agricultural sector provides the incomes of 80% of Mali's population and 75% of export earnings, and employs over one third of the labour force (AFDB, 2010). The region is influenced by a monsoon type of climate where large areas are inundated in the raining season (from May to September in the Bani and Niger headwaters). The IND is a network of tributaries, channels, swamps, and lakes providing vital habitats supporting livelihoods in fishing, farming, and stock farming. The total inundated area can reach around 30,000 km^2 in the flood season (Zwarts et al., 2005). These floodplains support the highest livestock density in Africa, and are increasingly threatened by a variety of anthropogenic pressures and unsustainable uses (WWF, 2008).

The focus area of the WETwin Mali case study is the Inner Niger Delta (IND). Vulnerability assessment includes the impacts of the upstream Niger and Bani catchments on the Inner Delta. Food production and food security for the one million people living in the Inner Niger Delta in Mali highly depends on extent and duration of the inundated area. The delta normally produces a surplus of fish, rice, and livestock to be exported to surrounding countries. However, the Niger River is not a constant resource, with fluctuating rains altering economic circumstances dramatically from year to year (WWF, 2008). A general assumption in this regard is: the larger the inundated area the higher the potential for food production (agriculture, livestock, and fishery). Fish landings and rice production may be halved, or further reduced, during years with low rainfall. The region remains economically unstable as a result, and foreign aid has had little effect. Since 1972, some US$100 million has been spent in the region, as the area's economy worsened (WWF, 2008).

The spreading of water- and vector-borne diseases, such as schistosomiasis and malaria is influenced by the state and the spatial structures of the inundated area(s). Climate variability and change as well as upstream water and agricultural management threaten the wetland ecosystem and livelihood of the human population in the Inner Delta. Observed climate trends show increasing temperatures (~0.155°C per decade) and decreasing rainfall (~86 mm per decade) for the period 1960 and 2007 (see section 2.4.2.1). Population growth is an additional pressure on food security and natural resources. Mali's population is projected to increase from ~13.5 million (2009) to ~40 million people in 2050 (see 2.3.2.1). Together with two dam projects planned at the Niger River, the probability of water scarcity problems is likely to increase in future. According to the African Development Bank Group (AFDB, 2010), inadequate control of water resources and the technical conditions of production is reflected in low productivity and agricultural incomes. Hence, adequate river basin management, integrating and emphasizing the importance of a functioning wetland ecosystem, is crucial to mitigate the impacts of projected climate and population development trends.

5.1.1 Important Future Drivers and Pressures

The most important future drivers and pressures identified in the Malian case study are the following:

- Climate variability and change
- Population growth
- Food production (food security)
- Land- and water management (extension of irrigated area by Office du Niger, planned Dam projects)
- Issues related to human health (sanitation, water quality, spreading of water- and vector borne diseases)

5.1.2 Vulnerability Framework

This section attempts to put the storylines (chapter 4) into the context of the vulnerability framework using the concepts of exposure, sensitivity, and adaptive capacity.

Exposure

The social-ecological system of the Inner Niger Delta is extremely exposed to climate variability and increasing water demands in the upstream catchment. Climate variability and change has a major impact on food security, economy (80% of the incomes are provided by the agricultural sector), and is threatening the wetland ecosystem. Projected climate change with decreasing rainfall and increasing temperature is worsening this. Projected population growth will lead to increasing food, water, and energy demands. As shown in section 2.3.2.1, Mali's population is projected to increase from currently 13.4 million (2009) to approximately 38 million people in 2050, assuming an annual growth rate of approximately 2.6%.

Furthermore, the human population of the Inner Delta is exposed to water- and vector borne diseases. The spreading of such diseases is strongly related to the omnipresence of shallow stagnant water and the deplorable sanitary conditions which in turn depend on water availability and water management.

The social-ecological system of the Inner Niger Delta is exposed to:

- Climate change and variability
- Water demand in the upstream catchment
- Population growth
- Water- and vector borne diseases

Sensitivity

The social-ecological system of the Inner Niger Delta is sensitive to changes in the water regime and to management practices in the Inner Delta. Changes in the water regime are considered here as external conditions, influenced by upstream water and agricultural management, climate change and variability as well as population growth. These external conditions determine the water flow into the Inner Delta. Due to the seasonality of rainfall, two periods are distinguished. Water availability during the rainy season and corresponding flood peaks determine the inundation area in the Inner Delta and minimal flows during the dry season are required to ensure the functioning of ecosystem services for the survival and livelihood of the human population. Hence, management practices in the Inner Delta are on the one hand constraint by external conditions but on the other hand are a product of a complex traditional management system of synchronized movement of different ethnic groups with the annual river flood. Today, the traditional systems of management have been discontinued, replaced by ineffective and confusing governmental regulations (WWF, 2008). The consequences of all these pressures are an over-exploitation of natural resources and are, thus, threatening ecosystem functions of the IND and the livelihood of people. Ecosystem functions in this regard are, for instance, provision of potential agricultural areas for rice production, provision of a healthy environment for fish, provision of protein-rich grasses for livestock, nutrient retention etc.

The social-ecological system of the Inner Niger Delta is sensitive to:

- Changes in the water regime (inflow into the Delta)
- Management practices in the Inner Delta

Adaptive Capacity

Adaptive capacity is the capacity of a socio-ecological system to cope with external and internal impacts and to implement measures to mitigate negative effects in order to ensure sustainability. In this regard, the socio-ecological system of the Inner Niger Delta has to combat adverse effects of climate change and variability, population growth, and water and agricultural management in the upstream basin as well as in the Delta region itself. Potential measures to mitigate these negative effects can be considered as indicators of adaptive capacity. According to the *Response* part of the DPSIR chains (Zsuffa et al., 2010) these potential measures include following aspects:

Improving Ecosystem Services

- Modifying upstream dam management to the benefit of IND, towards compromise between dam management objectives and downstream ecosystems. In order to quantify the impacts of dam and agricultural management, a comprehensive trade-off analysis is required here, but is not part of this report.
- Dredging the lateral canals to improve the lateral connectivity between ponds in the Inner Delta.
- Changing the current fishing strategies towards traditional management of fisheries (extensification).
- Changing farming practices
    - Irrigation farming
    - Growing crops that need less
- Financial compensation for herders for reduction of cattle stock.
- Developing ecotourism

Controlling Water- and Vector-borne Diseases

- Reduction of discharge of domestic wastewater
    - Installing (restoring) wastewater treatment plants
    - Installation of proper latrines
    -
- Pre-treatment of water (boiling, UV-treatment, filtering…)
- Raising awareness among local people for using alternative sites for bathing and water extraction.
- Installation of wells in the settlements
- Medical treatment
- Controlling the hydrological regime of the IND with the help of the upstream dams.

5.1.3 Qualitative Assessment

The following matrix (Table 5.1) illustrates the qualitative impact assessment for the three storylines developed for the case study of the Inner Niger Delta (IND) in Mali. The social-ecological system of the IND is sensitive to changes in the hydro-morphological regime. Beside climate change and variability, management of dams and reservoirs along the Niger River influence the flow regime and the flow into the Inner Delta. The impact matrix illustrates the impacts of these management options on the social-ecological system of the IND and is based on expert judgment. We distinguish impacts of dam management on the IND system during the wet and dry season, because a certain measure can have positive impacts in the dry season and negative impacts in the wet season, and vice versa.

The impacts of management options under the three global scenarios are neglected in the qualitative assessment. It is thus an assessment of general impacts of management options on the storylines. The likelihood to favour certain management options might be different in the scenarios and will be tackled in the quantitative assessment (deliverable 5.2).

Table 5.1. *Qualitative Impact Assessment of Dam Management Options on Socio-Ecological System of the IND*

	Mgt. option →	**Irrigation**		**Energy production**		**Minimum flows**	
	Season **Impact on ↓**	**wet**	**dry**	**wet**	**dry**	**wet**	**Dry**
Storyline 1	**Diseases**	0	--	?	?	?	?
Storyline 2	**Ecosystem Functions**	-	--	-	+	0	++
Storyline 3	**Retention / Purification**	?	?	?	+	0	++

Table 5.2. *Legend of Table 5.1*

Category	Impact
++	Very positive
+	Positive
0	No expected impact
-	Negative
--	Very negative

5.1.3.1 Storyline: Diseases

Assessment of the vulnerability of the social-ecological system of the Inner Niger Delta to spreading of vector- and water-borne diseases due to different dam management operations under climate change and population growth in the period from 2010 to 2050.

Since, the spreading of vector- and water-borne diseases significantly depends on the omnipresence of shallow stagnant water, knowledge of flood extents, water levels, and the spatial and temporal changing structures and distances of ponds is necessary. Therefore, it is almost impossible to qualitatively assess the vulnerability of the socio-ecological system of the IND to changed dam management. A quantitative modelling approach is required here to support this and to simulate the impact of different water inflows to the presence of ponds, water levels, and distances.

Max. inundation area is an indicator for Malaria, high velocity = bad breeding conditions for Mosquitoes and snales. But high velocity means that cholera virus can spread faster.

Impact of Dam Management: Irrigation

Zwarts et al., (2005) assume an increasing spread of diseases due to expansion of irrigation zones. Thus, Table 5.1 indicates "very negative" impact of dam management towards irrigation purposes on spreading of diseases during the dry season.

Impact of Dam Management: Energy Production

Impact of Dam Management: Minimum Flows

Impact of Population Growth

Mali's population is assumed to increase in all three global change scenarios (G-Ec, G-Env, R-Ec) up to 2050. In order to feed the growing population in the future it is likely that the irrigated agricultural area will be expanded. As shown in the vulnerability matrix (Table 5.1) an extension of the irrigation practices is assumed to have a *very negative* impact on the spreading of vector- and water-borne diseases, particularly during the dry season.

A growing population will also increase the energy demand. The energy demand per capita might be different in the three scenarios, which has to be tackled in the quantitative assessment.

Impact of Climate Change and Variability

As shown in chapter 2.4.2.1 air temperature is expected to increase and it is very likely that annual rainfall amounts will decrease in the Upper Niger catchment. To what extend and how patterns will change will be investigated in the quantitative assessment (D5.2). How climate change and variability will affect the spreading of vector and water-borne diseases is not yet clear.

5.1.3.2 Storyline: Ecosystem Functions

Assessment of the vulnerability of ecosystem functions and services of key habitats in the Inner Niger Delta to different dam management operations under climate change and population growth in the period from 2010 to 2050.

Key habitats in this context are flood forests, bourgou fields (Echinochloa stagnina: Burgu Millet, hippo grass which is important for livestock), breeding ground for fish and fish eating waterbirds, and areas to cultivate floating rice. This storyline addresses several ecosystem services with impacts on many income sectors such as fishery, agriculture, and livestock. Ecosystem services are considered to be mainly impacted by different inflow rates to the Inner Delta.

Impact of Dam Management: Irrigation

Dam management that prioritizes irrigation is assumed to have negative impacts on ecosystem functions within the Inner Delta during the wet season, because flood peaks are reduced which are required to inundate large areas. However, the impact of irrigation is assumed to be very negative during the dry season, because it reduces discharge into the Inner Delta in the low flow period. This can cause severe damage to the ecosystem and its functions if required minimum flows can not be assured.

Impact of Dam Management: Energy Production

The impact of dam management focussing on energy production is twofold. During the wet season river discharge is used to fill the reservoirs. The consequence is that flood peaks are reduced that are required to inundate large areas in the IND. A reduction of inundated areas is thus a reduction of areas for important key habitats.

In contrast to this, dam management prioritizing energy production would release more water from the storages during the dry period than under natural conditions. This would probably improve the conditions for key habitats during this period. Here it should be investigated if too much water could also harm the ecosystem which is adapted to two extreme seasons.

Impact of Dam Management: Minimum Flows

Dam management focussed on minimum flows is somewhat similar to the management favouring energy production. A difference could be that flood peaks during the rainy season are not reduced in order to guarantee optimal flooding of the IND. However, such a strategy could definitely help to mitigate negative effects of climate change and variability, particularly during the dry season.

Impact of Population Growth

Mali's population is projected to increase in all three global change scenarios (G-Ec, G-Env, R-Ec) up to 2050. In this connection the demand for food, natural resources, and land for agriculture will increase. Consequently, population growth can be considered as additional pressure for the conservation or survival of key habitats.

Impact of Climate Change and Variability

As shown in chapter 2.4.2.1 air temperature is expected to increase and it is very likely that annual rainfall amounts will decrease in the Upper Niger catchment. To what extend and how patterns will change will be investigated in the quantitative assessment (D5.2). How climate change and variability will affect the key habitats in the IND is not entirely clear, but it is likely that projected changes are not to the benefit of habitats.

5.1.3.3 Storyline: Retention / Purification

Assessment of the vulnerability of water purification functions and nutrient retention in the Inner Niger Delta to different dam management operations under climate change and population growth in the period from 2010 to 2050.

Water purification and nutrient retention functions in a wetland are determined by various physicochemical and biological parameters, such as flow velocity, turbulence, travel distance, vegetation etc. Main input to the impact assessment are different inflow scenarios according to the different management options, climate change and variability as well as population growth. These inflow scenarios are then the basis to model the wetland's retention capacity assuming different nutrient inputs.

Impact of Dam Management: Irrigation

Due to missing indicators and thresholds, the effects of irrigation agriculture on purification and retention are not yet entirely clear in this context.

Impact of Dam Management: Energy Production

It is assumed that dam management prioritizing energy production is likely to have a positive effect on ecosystem health during the dry season. Therefore it is likely that purification and retention functions would benefit. The effect of reduced peak flows on these functions during the wet season is not yet known.

Impact of Dam Management: Minimum Flows

Dam management focussed on minimum flows is somewhat similar to the management favouring energy production. A difference could be that flood peaks during the rainy season are not reduced in order to guarantee optimal flooding of the IND. However, such a strategy could definitely help to mitigate negative effects of climate change and variability, particularly during the dry season.

Impact of Population Growth

Mali's population is projected to increase in all three global change scenarios (G-Ec, G-Env, R-Ec) up to 2050. In this connection the demand for food, natural resources, land for agriculture, and the production of solid waste and nutrient loads into the river will increase in total. Assuming increasing living standards could worsen this situation, because it usually goes along with increasing consumption of natural resources per capita. However, the effects of increasing living standards are diverse and not all of them are negative of course. GDP development in Mali is assumed to increase faster in the globalization scenarios than in the regionalization scenario.

Impact of Climate Change and Variability

As shown in chapter 2.4.2.1 air temperature is expected to increase and it is very likely that annual rainfall amounts will decrease in the Upper Niger catchment. To what extend and how patterns will change will be investigated in the quantitative assessment (D5.2). How climate change and variability will affect specific ecosystem functions in the IND is not entirely clear, but it is likely that projected changes are not to the benefit of these functions.

5.2 Uganda (Nabajjuzzi wetland)

5.2.1 Important Future Drivers and Pressures

The most important future drivers and pressures identified in the Ugandan (Nabajjuzzi) case study are the following:

- Climate change and variability
- Water supply (quantity and quality)
- Population growth
- Urbanization

5.2.2 Vulnerability Framework

This section attempts to put the storylines (chapter 4) into the context of the vulnerability framework using the concepts of exposure, sensitivity, and adaptive capacity.

Exposure

The social-ecological system of Nabajjuzzi is extremely exposed to population growth and urbanization. As shown in section 2.3.2.1, Uganda's population is projected to increase from currently 32.4 million (2009) to approximately almost 100 million people in 2050, assuming an annual growth rate of approximately 2.7% (CIA, 2010).

The system is also exposed to climate variability and change, but it is not yet clear to what extent. This will be investigated in the connection with drinking water supply for the city of Masaka.

The social-ecological system of Nabajjuzzi is exposed to:

- Climate change and variability
- Population growth / urbanization

Sensitivity

It is assumed that the Nabajjuzzi system is sensitive to changes in the water regime (quantity) and to changes in nutrient inputs by waste water discharge (water quality). To what extend the system is sensitive to the stressors and what the critical thresholds for sustainability are, is not yet know.

The social-ecological system of Nabajjuzzi is sensitive to:

- Water abstraction
- Waste water discharge

Adaptive Capacity

Adaptive capacity is the capacity of a socio-ecological system to cope with external and internal impacts and to implement measures to mitigate negative effects in order to ensure sustainability. In this regard management options and their effectiveness determine adaptive capacity. The management options to ensure water supply and sustain ecological functions of the wetland are the following in this study:

- **Increasing** water **intake** from current intake point (now new intake point)
- Implementation of a **new intake** point
    - Downstream at Nakaiba arm (as envisaged)
    - Alternative location for new intake
- **Replacing** the old intake by the new intake point
- **Reducing** the input of **organic loads**
    - Papyrus management
    - Waste water treatment (at household or community level)
- Additional drinking water supply by **ground water** (construction of wells)

5.2.3 Qualitative Assessment

The following matrix (Table 5.3) illustrates the qualitative impact assessment for the two storylines developed for the Nabajjuzzi case study in Uganda. Impacts during dry and wet seasons (periods) are distinguished.

The impacts of management options under the three global scenarios are neglected in the qualitative assessment. It is thus an assessment of general impacts of management options on the storylines. The likelihood to favour certain management options might be different in the scenarios and will be tackled in the quantitative assessment (deliverable 5.2).

Table 5.3. *Qualitative Impact Assessment of Management Options on the Nabajjuzzi Socio-Ecological System*

	Mgt. option →	Increasing In-take		New Intake		Replacing		Reducing org. loads		Ground water	
	Season Impact on ↓	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry
Storyline 1	w. supply	+	-	+	+	?	?	0	0	+	+
	w. quality	?	-	?	?	?	?	+	+	+	+
Storyline 2	w. quantity	-	-	-	-	-	-	0	0	0	0
	w. quality	-	-	-	-	-	-	+	+	0	0

Table 5.4. *Legend of Table 5.3*

Category	Impact
++	Very positive
+	Positive
0	No expected impact
-	Negative
--	Very negative

5.2.3.1 Storyline 1

Assessment of the vulnerability of water provisioning by the Nabajjuzzi wetland to the Masaka supply area to climate change/variability and population growth in the period 2010 to 2050.

It has to be emphasized here that this storyline focuses only on water provisioning to the Masaka supply area, neglecting ecological aspects. Hence, the two parameters affected by management options and external and internal drivers and pressures are *water supply* and *water quality*. If the impact on water supply is negative or very negative, this means that water supply for Masaka (not the downstream wetland) is not guaranteed in the respective season. The same holds for water quality, it refers to the quality of water provided to the Masaka supply area and not the downstream catchment.

Impact of Management Option: Increasing Intake

In general it is assumed that increasing the water intake at the current intake point is very likely to have a negative impact on water supply and quality during the dry period. A more detailed description of the current situation is necessary in order to evaluate this adequately.

than during the wet period. However, in both seasons the impact is considered to be negative, but to different degrees. Focusing

Impact of Management Option: New Intake

Impact of Management Option: Replacing

Impact of Management Option: Reducing Organic Loads

Impact of Management Option: Ground Water

Impact of Population Growth and Urbanization

Impact of Climate Change and Variability

5.2.3.2 Storyline 2

Assessment of the vulnerability of the Nabajjuzzi ecosystem and its riparian population downstream of the city of Masaka to increased water abstraction, climate change/variability and population growth in the period 2010 to 2050.

Impact of Management Option: Increasing Intake

Impact of Management Option: New Intake

Impact of Management Option: Replacing

Impact of Management Option: Reducing Organic Loads

Impact of Management Option: Ground Water

Impact of Population Growth and Urbanization

Impact of Climate Change and Variability

5.3 Uganda (Namatala wetland)

5.3.1 Important Future Drivers and Pressures

The most important future drivers and pressures identified in the Ugandan (Namatala) case study are the following:

- Climate change and variability
- Population growth
- Agriculture (agricultural encroachment; practices are risky and less productive)

5.3.2 Vulnerability Framework

This section attempts to put the storylines (chapter 4) into the context of the vulnerability framework using the concepts of exposure, sensitivity, and adaptive capacity.

Exposure

The social-ecological system of the Namatala wetland is extremely exposed to impacts of man-made modifications of the natural system, namely the removal of the natural papyrus cover to the benefit of agricultural land. The highly modified and artificial wetland is thus more and more exposed to impacts of climate change and variability. Population growth has been addressed as additional stressor increasing the demand for food production, natural resources, drinking water, and increasing nutrient loads in form of waste water discharge and maybe fertilizer applications.

The social-ecological system of Nabajjuzzi is exposed to:

- Agricultural encroachment and unsustainable practices
- Climate change and variability
- Population growth

Sensitivity

Important ecosystem functions, such as water purification capacity and water regulation of the highly modified Namatala wetland are very likely to be sensitive to current intensive management practices. The unsustainable wetland management has impacts on the water regime and water quality.

The social-ecological system of Nabajjuzzi is sensitive to:

- Changed water regime
- Increasing nutrient inputs

Adaptive Capacity

Management options to mitigate and cope with external and internal impacts on sustainability of the social-ecological system of the Namatala wetland determine its adaptive capacity. Conditions that hinder the implementation of such measures, a lack of financial resources or a lack of reasonable alternatives for income for instance, reduce adaptive capacity. The proposed management options in the Nabajjuzzi wetland are:

- Land use change, conversion of farmland to papyrus
- Different papyrus harvesting regimes
- Construction of a waste water treatment plant

5.3.3 Qualitative Assessment

The following matrix (Table 5.5) illustrates the qualitative impact assessment of the storyline developed for the Namatala case study in Uganda. Impacts during dry and wet seasons (periods) are distinguished.

The impacts of management options under the three global scenarios are neglected in the qualitative assessment. It is thus an assessment of general impacts of management options on the storylines. The likelihood to favour certain management options might be different in the scenarios and will be tackled in the quantitative assessment (deliverable 5.2).

Table 5.5. *Qualitative Impact Assessment of Management Options on the Namatala Socio-Ecological System*

	Mgt. option →	Land use change		Papyrus regime		WWTP	
	Season Impact on ↓	wet	dry	wet	dry	wet	dry
Storyline 1	w. quantity						
	w.quality						

Table 5.6. *Legend of Table 5.5*

Category	Impact
++	Very positive
+	Positive
0	No expected impact
-	Negative
--	Very negative

Impact of Management Option: Land use change

Impact of Management Option: Papyrus regime

Impact of Management Option: WWTP

Impact of Population Growth

Impact of Climate Change and Variability

5.3.3.1 Impact Assessment of Management Options on Storyline 1

Assessment of the vulnerability of the wetland functions (water quantity & quality regulation) to increased wastewater loads, climate variability and rice production in the period 2010 to 2050.

Changing partly land use from farmland to papyrus is assumed to have an impact on the water regime. In contrast to farmland, a papyrus cover is likely to reduce flow velocity by increasing the channel roughness. Depending on its condition and age, the papyrus cover has an impact on evapotranspiration. According to Rijks (1969), evaporation from an old papyrus stand is 45-75% of Penman estimates of evaporation from open water. Regarding water quality, it is known that papyrus swamps have the capacity to remove organic nutrients from sewage effluents. The effectiveness of nutrient removal depends on the conditions of the papyrus vegetation.

In order to model the effect of a papyrus swamp on water regime and quality or to implement reasonable papyrus harvesting/management strategies, optimal conditions and constraints for this vegetation type must be known (flow velocity, water levels, age of the plants etc.).

5.4 South Africa

5.4.1 Important Future Drivers and Pressures

Based on the analysis of the DPSIR chains the following drivers and pressures have been identified:

Education / environmental awareness

Poor environmental management practices

Financial issues

Agriculture, food production

Population growth

Climate change and variability (although not yet an element in the DPSIR chain, based on discussions in the consortium climate change and variability are considered to be important drivers)

(Erosion, as a consequence of a flood event, maybe a state not a pressure)

5.4.2 Vulnerability Framework

This section attempts to put the storylines (chapter 4) into the context of the vulnerability framework using the concepts of exposure, sensitivity, and adaptive capacity.

Exposure

Sensitivity

Adaptive Capacity

5.4.3 Qualitative Assessment

The impacts of management options under the three global scenarios are neglected in the qualitative assessment. It is thus an assessment of general impacts of management options on the storylines. The likelihood to favour certain management options might be different in the scenarios and will be tackled in the quantitative assessment (deliverable 5.2).

5.5 Ecuador

5.5.1 Important Future Drivers and Pressures

5.5.2 Vulnerability Framework

This section attempts to put the storylines (chapter 4) into the context of the vulnerability framework using the concepts of exposure, sensitivity, and adaptive capacity.

Exposure

Sensitivity

Adaptive Capacity

5.5.3 Qualitative Assessment

The impacts of management options under the three global scenarios are neglected in the qualitative assessment. It is thus an assessment of general impacts of management options on the storylines. The likelihood to favour certain management options might be different in the scenarios and will be tackled in the quantitative assessment (deliverable 5.2).

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