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Climate change, vulnerability and adaptation in North Africa with focus on Morocco

University of Hamburg
Research Group Climate Change and Security

Working Paper
CLISEC-13

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Abstract

Our study links environmental impacts of climate change to major socio-economic and agricultural developments in North Africa. We jointly investigate climate projections, vulnerability, impacts, and options for adaptation. Precipitation in North Africa is likely to decrease between 10 and 20%, while temperatures are likely to rise between 2 and 3°C by 2050. This trend is most pronounced in the north-western parts of northern Africa as own model results suggest. Population is likely to grow by more than 50% until 2050. The combination of decreasing supply and increasing demand aggravates the stressed water situation in the region. We compare the vulnerabilities and conflict implications of climate change in Algeria, Egypt, Libya, Morocco, and Tunisia. The adaptive capacities vary strongly from state to state. Climate change will likely have the strongest effect on Morocco where the agricultural sector is of high importance for the country's economy and for 57% of poor people. Based on our comparison, we choose Morocco for a more detailed analysis of impacts and adaptation options. To increase resilience against climate change, agricultural policies should focus on conservation of soil quality, rangeland vegetation, and balanced groundwater usage, since prospects of further increasing primary agricultural productivity are limited. Therefore, an increase of added value should be a major objective. Our model results suggest a considerable potential of replacing the use of firewood by electric energy to sustain pastoral productivity. Failure to implement these policies increases the risk that climate change will contribute to inequality and instability in North Africa.

Keywords: *Climate change, Vulnerability, Adaptation, Agriculture, Conflict, North Africa*

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Abbreviations

CIA: Central Intelligence Agency

CORDEX: Coordinated Regional Climate Downscaling Experiment

ECHAM: European Centre Hamburg Model

ENSO: El Niño-Southern Oscillation

FAO: Food and Agriculture Organization of the United Nations

GDP: Gross Domestic Product

HDI: Human Development Index

HWSI: Hydrological Water Stress Index

IPCC: Intergovernmental Panel on Climate Change

MASEN: Moroccan Agency for Solar Energy

mts: metric tons

NAO: North Atlantic Oscillation

PMV: Plan Maroc Vert (Green Morocco Plan)

PPP: Purchasing Power Parity

PRIO: Peace Research Institute Oslo

RWPI: Reversed Water Poverty Index

SPEED: Social, Political and Economic Event Database

SRES: Special Report on Emissions Scenarios

SST: Sea Surface Temperature

SWSI: Social Water Scarcity Index

UCDP: Uppsala Conflict Database Program

UNDP: United Nations Development Programme

WBGU: German Advisory Council on Global Change

WHO: World Health Organisation

WPI: Water Poverty Index

1. Introduction

Climate change poses a significant challenge for North Africa, affecting and interacting with both environmental and anthropogenic systems in the region. Among the variables of interest are environmental degradation, agricultural productivity, food security, population growth and economic and societal (in-)stability. So far, the majority of research articles have focused on climate change and its interrelation with one or two of the aforementioned variables (e.g. Agoumi 2003, Bekkoussa 2008, Hadid, Meddi 2009; Lhomme 2009, Mougou, Beckouche 2010 Brauch 2010).

The present article aims to draw a wider, although not exhaustive, picture of climatic and social changes in North Africa by integrating perspectives from climate science, social geography, conflict research, and environmental sciences. We jointly investigate some major interrelations between climate projections, vulnerability, impacts, policy responses and options for adaptation.

The starting point of our investigation is a description of the physical climate change as presently observed and its projections for the 21st century. We address the uncertainties of projections and their consequences for extreme events using own model runs as well as data from the literature (section 2).

Against this background, we give an overview of the vulnerability to climatic changes of the five North African states Algeria, Egypt, Libya, Morocco and Tunisia (see Fig. 1). The overview servers two purposes: First, it allows us to discuss security concerns of climate change which have been raised even prior to the riots in Tunisia, Egypt and Libya in 2011 (see WBGU 2007, Igelsias 2010, Smith and Vivekananda). Second, the overview enables us to identify countries which are particularly vulnerable to climate change and hence suitable for a further discussion. Morocco is particularly vulnerable, predominantly because of its high sensitivity to climatic changes and its limited adaptive capacities (section 3).

Focussing on Morocco, we assess the impacts of climate change on agriculture and society. It turns out that impacts of climate change can be aggravated by unsustainable policy responses and agricultural practices. Based on this finding, we investigate a set of adaptation options using data from local research projects. In addition, an own bio-economic model is used to explore the possibility of increasing resilience of pastoral livestock husbandry in semi-arid rangelands. One option is to replace firewood by other energy sources such as solar power (section 4). The insights from Morocco are supposed to reveal linkages between climate change, agricultural practices and socio-economic developments which are also relevant for adaptation in other North African countries.

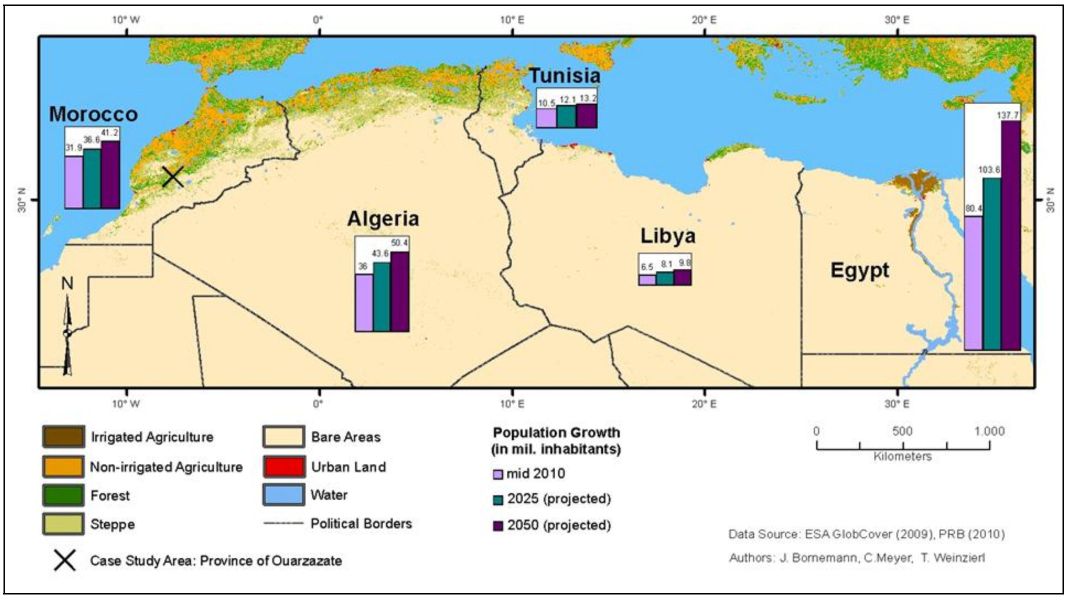

Fig. 1 Land use and population growth in North Africa (own representation based on European Space Agency 2010; PRB 2010)

2. Climate change in North Africa

2.1 Recent climate characteristics

Precipitation of North Africa is characterized by a wet season in winter and dry conditions in summer. The rainy season, which starts in October and lasts until April, has its maximum in the months from December to February (Endlicher 2000; Lionello, Malanotte et al. 2006). Additionally the whole region is characterized by high inter-annual precipitation variability. Thus, long-term mean precipitation, especially in the southern region of North Africa, reflects averages over many dry years and some relatively humid years.

A generalized overview of historical trends in the recent past and likely future trends under enhanced greenhouse warming conditions for temperature and precipitation in the North African countries is given in Table 1. For north-eastern Morocco and north-western Algeria, several studies point to below average annual rainfall rates which have prevailed since about the mid-1970s (Hertig 2004; Fink, Piecha et al. 2008; Meddi, Assani et al. 2010). Also for the southern parts of the Moroccan Atlantic coast as well as for the Atlas Mountains several periods of below average precipitation occurred in the second half of the 20th century in the winter season, for example in the period 1971 to 1975 and in the period 1979 to 1983, but also some positive anomalies can be found around the late 1980s and 1990s (Hertig 2004). Due to the observed changes, a general tendency towards warmer and drier conditions can be found in the last decades for the above mentioned regions (Gerstengarbe and Werner 2007; Born, Piecha et al. 2008). In contrast to the predominantly negative precipitation evolution in the western parts of Northern Africa, no pronounced precipitation trends have been observed for the eastern regions such as north-eastern Algeria (Meddi and Talia 2008), Mediterranean Tunisia (Hertig 2004), central Tunisia (with some decadal variability, Kingumbi, Bargaoui et al. 2005), and the Mediterranean parts of Libya and Egypt (Hertig 2004) during the last decades of the 20th century.

Table 1 Generalized overview of recent and likely climatic trends in North Africa (sources in text)

	Recent trends		Future trends	
State	temperature	precipitation	temperature	precipitation
Algeria	+	-	+	-
Egypt	+	o	+	-
Libya	+	o	+	-
Morocco	+	-	+	-
Tunisia	+	o	+	-

\+ increase - decrease o no change

With respect to seasonal predictions, Born et al. (2010) find that the skill of simple statistical seasonal rainfall predictions is limited. Using multivariate statistical analyses, Hertig and Jacobeit (2010; 2010) show that precipitation in February in the Atlas Mountains of Morocco, regional temperatures in Algeria and Tunisia in the month of May, and December temperatures in the western parts of Northern Africa can be predicted by taking preceding sea surface temperature anomalies as predictors. Thus, it becomes evident that there is some skill regarding seasonal predictions of temperature and precipitation (see Slimani, Cudennec et al. 2007 for Tunesia). In the scope of possible future enhancements of such predictions, they could become more important, especially in the context of the additional challenges due to climate change.

2.2 Future climate change

For Northern Africa climate change studies indicate that annual precipitation is likely to decrease during the course of the 21st century (Gibelin and Déqué 2003; Giorgi and Bi 2005; Rowell 2005). According to the Regional Model REMO, precipitation in North Africa is likely to decrease between 10% and 20% until the year 2050 under SRES A1B scenario conditions (Paeth, Born et al. 2009). For winter precipitation, decreases are modelled by Räisänen et al. (2004), with an emphasis of strongest reductions on the Moroccan region. An assessment of precipitation changes within the IMPETUS project (An integrated approach to the efficient management of scarce water resources in West Africa) shows that Moroccan rainfall might be reduced in the period 2011-2050 between 5% (mountainous areas) and 30% in the southern regions for the SRES A1B scenario and by 5% and 20% for the B1 scenario (Christoph, Fink et al. 2010). Projected precipitation decreases in winter are controlled by processes which involve a systematic shift of the cyclone tracks to a more polward position. This leads to drier conditions in North Africa. In summer a positive feedback with decreased soil moisture values has been considered. However, it has to be kept in mind that the exact spatial location of the polar front in a future warmer climate is still highly uncertain. Furthermore atmospheric humidity has to be taken into account because of the increased moisture holding capacity of the atmosphere under warmer conditions.

Precipitation

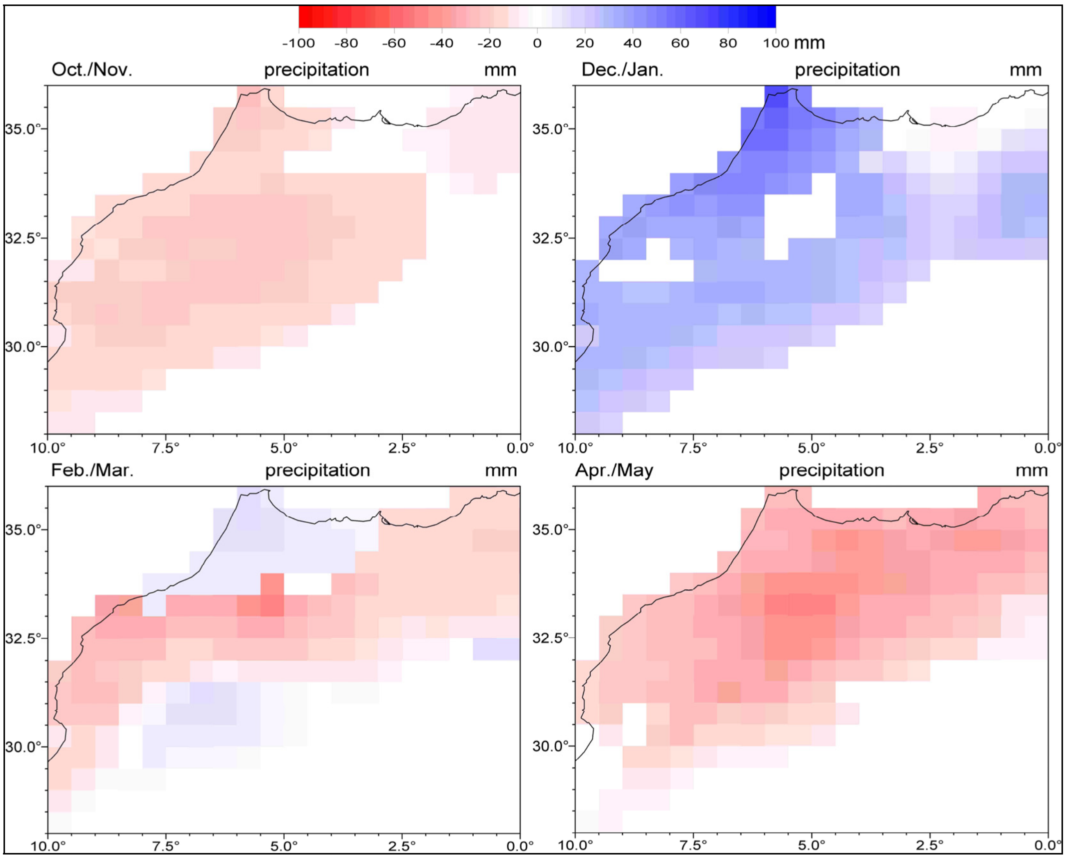

Fig. 2 Changes of Mediterranean precipitation for the main rainy season from October to May according to statistical downscaling assessments using ECHAM4/OPYC3 predictors (1000hPa-/500hPa- geopotential heights and 1000hPa-specific humidity). Differences of the mean 2-month precipitation between the periods 2071-2100 and 1990-2019 in mm. Statistical downscaling technique: Canonical Correlation Analysis. Scenario: SRES-B2

Statistical downscaling of precipitation for a region covering the western parts of Northern Africa shows rainfall increases in December/January of up to about 60 mm in the period 2071-2100 compared to the time period 1990-2019 (Fig. 2). The results are based on assessments of precipitation changes under the moderate SRES B2 scenario assumptions using a statistical downscaling technique. A detailed description of the downscaling technique can be found in Hertig and Jacobeit (2008). As can be seen from Figure 2, there are negative precipitation changes at the beginning of the rainy season in October/November. However, in high winter (December/January) substantial increases are estimated. A simulation with a local model within the IMPETUS project shows more intense precipitation events as a result of enhanced humidity advection (Christoph, Fink et al. 2010). In the statistical assessment of the present paper, weak increases continue in some sub-areas in February/March (Fig. 2). Thereafter, the whole region is affected by drier conditions in spring (April/May). The signal-to-noise-ratio (the rainfall difference of the two 30-year periods in relation to natural variability) of the precipitation reduction in spring is greater than one, indicating that the climate change signal is greater than the recent natural variability. A study by Palutikof and Wigley (1996) also estimates decreased rainfall south of the Mediterranean Sea during spring. Around this drier region, the north-western parts of northern Africa stand out as a region of most pronounced decreases in precipitation. This was also reported by Jacobeit (1994). Summarizing the results of the statistical downscaling, a shortening and at the same time an increase in rainfall amount of the wet season arises for the western parts of North Africa.

Temperature

Regarding temperature the dynamical regional model REMO suggests a temperature rise in North Africa between 2 and 3°C by 2050 under A1B scenario conditions (Paeth, Born et al. 2009). The temperature rise for Morocco is estimated to 1.2°C in the SRES A1B and 1°C in the B1 scenario. Both scenarios yield a slightly more pronounced increase in the mountain region (Christoph, Fink et al. 2010). An application of regional and global climate models by Patricola and Cook (2010) for Northern Africa shows a very strong warming of about 6°C over north-western Africa in the 21st century compared to the 20th century. Also, when looking at results from statistical downscaling by Hertig and Jacobeit (2008), a temperature rise becomes visible for western North Africa. The temperature assessment indicates increases of mean temperature in all months of the year, with largest warming rates in summer (June/July) and autumn (Oct./Nov.) of partly more than 4°C until the end of the 21st century. The lowest warming rate is assessed for the winter months December and January with values of up to about 1°C. Overall the spatial warming pattern has an emphasis on the mountainous areas of the Atlas Mountains, and weakens towards the coastal areas of the Atlantic Ocean and the Mediterranean Sea.

Extreme events

Concerning extremes, more precisely droughts, the risk of these events is likely to increase in Northern Africa. For Europe and western North Africa Räisänen et al. (2004) find that average precipitation reduction is associated with a reduced number of precipitation days rather than with reduced precipitation intensity. Voss et al. (2002) determine a significant prolongation of very long dry spells (10-year return values of annual maximum dry spells) in the period 2060-89 compared to 1970–99 for Northern Africa. A study of Beniston et al. (2007) also indicates considerable drying over western Mediterranean North Africa.[1] The main features are reduced intensity of precipitation, and earlier onset and longer duration of drought (i.e. continuous period of days with no precipitation). This finding is in accordance with the study of Tebaldi et al. (2006) who also find a significant increase in dry days (defined as the annual maximum number of consecutive dry days).

[1] For instance, see Bekkoussa for Algeria and Mathlouti for Tunisia.

Uncertainties

As the previous discussion already suggests, projections of future climate change for Africa exhibit considerable uncertainties. The IPCC concludes that it is necessary to improve the assessments for the African regions. The global general circulation models still have major difficulties over Africa, for example unrealistic climate variability in the Sahel zone or a southward displacement of the Atlantic inter-tropical convergence zone (Christensen, Hewitson et al. 2007). In some projections the greening of the Sahara is a possibility (see Claussen and Gayler 1997; Claussen, Brovkin et al. 2003). Dynamical and statistical downscaling assessments also need major improvements for the African domain. For instance it is necessary to gain a better understanding of climate variability in this region, which involves the inclusion of specific feedback mechanisms e.g. of the oceans and of land use change. In recent years more attention has been turned to this region as for example by the IMPETUS project or the CORDEX (Coordinated Regional Climate Downscaling Experiment) initiative, which tries to enhance regional climate change information especially for Africa.

3. Vulnerability of North Africa

This section gives an overview of the vulnerability to climate change of the five North African states, Algeria, Egypt, Libya, Morocco and Tunisia. So far, the concept of vulnerability lacks one generally accepted and precise definition (see Cutter 2003; Vincent 2004; Füssel 2007; Scheffran 2010). Yet, three elements of vulnerability can be identified as consistent throughout the literature: i) exposure to climate change, ii) sensitivity to climate change, and iii) adaptive capacity (Adger 2006; Smit and Wandel 2006; Heltberg, Siegel et al. 2009). These elements are reflected by the IPCC, who defines vulnerability as “a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity” (IPCC 2007:883). Exposure to climate change has been described in the previous section; sensitivity and adaptive capacity are subject of this section (see Fig. 3).

With respect to the overview character of this section, the discussion of sensitivity focuses on agriculture which is most directly affected by climate change (Mougou, Mansour et al. 2011).[2] The indicators used to analyze the sensitivity and the adaptive capacity were chosen based on recognition in the literature, consistency and availability.[3] The resulting catalogue of indicators is similar to the one suggested by Brooks (2006). In 3.3 the findings on sensitivity (3.1) and adaptive capacity (3.2) are combined with the climate change exposure (section 2) to assess the vulnerability and to draw conclusions for potential conflict implications.

[2] For an assessment of climate change impacts on tourism see Hein, for the impacts on the energy sector see Giannakopoulos et al. (2009).

[3] A discussion of different indicators of vulnerability can be found in Brooks et al. (2005), Adger (2006; Adger, Lorenzoni et al. 2009), Heltberg et al. (2009), Füssel and Klein (2006), Cutter (2003), Yohe and Tol (2002). See also UNFCCC (2007).

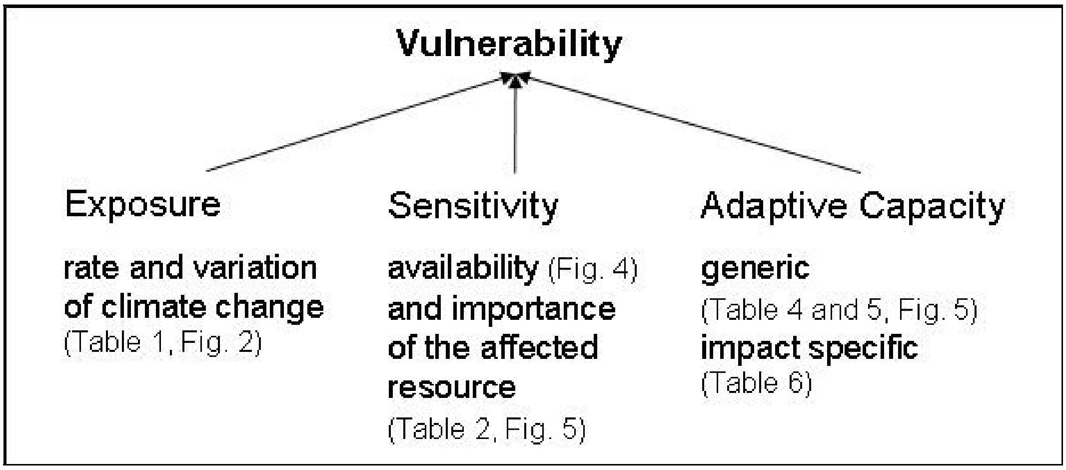

Fig. 3 Elements of vulnerability (own representation based on IPCC 2007)

3.1 Sensitivity

While closely related to exposure, sensitivity is “the degree to which a system is affected, either adversely or beneficially, by climate variability or change” (IPCC 2007:881). In the context of this paper we focus on the resource dimension of sensitivity as suggested by Barnett and Adger (2007). Referring to the sensitivity element of vulnerability, Barnett and Adger argue that the vulnerability of people “depends on the extent to which they are dependent on natural resources and ecosystem services [and] the extent to which the resources and services they rely on are sensitive to climate change” (2007:641). The following section therefore discusses the availability of the affected resources prior to the climate stimuli (see Adger 1999) and the importance of the resource for the system.

Water availability

Water is the resource most directly and strongly affected by the climatic changes discussed in section 2. Higher temperatures and less (reliable) precipitations will likely decrease the overall availability of water in North Africa. Already, water is a scarce resource in the whole region. Depending on the index used, the North African countries are either termed stressed or scarce (Fig. 4). According to the Hydrological Water Stress Index (HWSI) Algeria and Tunisia face the highest level of water scarcity while in Egypt and Morocco water is less scarce (Fig. 4)[4]. If the human development is taken into account the situation seems to be less dramatic (see SWSI in Fig. 4). The Social Water Scarcity Index (SWSI) indicates water stress in Egypt and Morocco and water scarcity in the remaining

[4] Libya has by far the lowest renewable water resources; 60 million m³ compared to the second lowest Morocco with 4.6 billion m³ in 2008 (FAO 2010). This causes its water indices (HWSI of 1050 and SWSI of 797) to lie way out of range. Additionally no water poverty index was available. Therefore Libya is excluded from the discussion of water indices.

countries. Although the SWSI to some extent takes the social adaptive capacity of the affected society into account (see following sections), it does not say anything about other relevant factors such as the distribution or the quality of the water. In this respect, the Water Poverty Index (WPI) is more suitable as it is composed out of four indices on: water resources, access, capacity and environment (see Lawrence, Meigh et al. 2003). Even though the WPI should be seen as an "order-of-magnitude estimate" (World Resources Institute 2008:213), it still partially reverses the statement of previously discussed indices. While both the HWSI and the SWSI characterize the water situation in Morocco to be comparatively less serious, the country is the water poorest according to the WPI (see Reversed Water Poverty Index (RWPI) in Fig. 4).

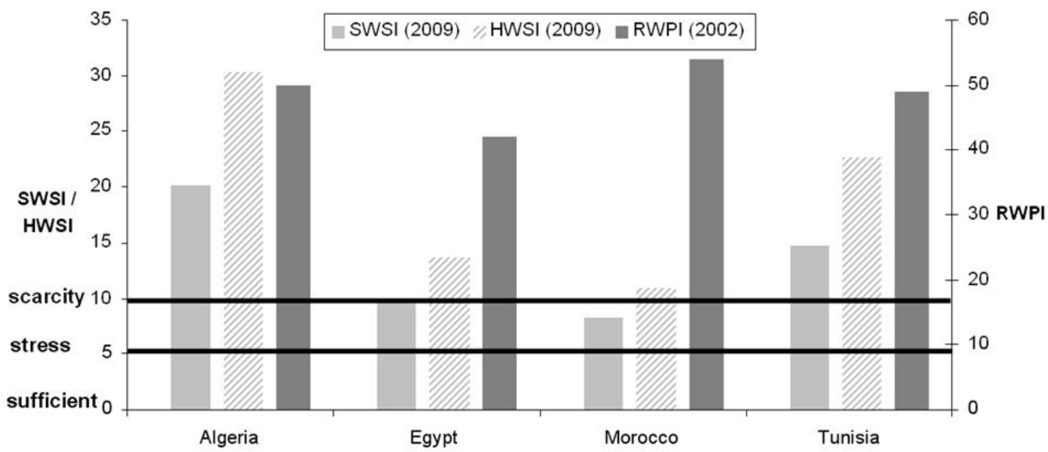

Fig. 4 Comparison of water indices for North Africa (own calculations based on Ohlsson 2000; World Resources Institute 2008; FAO 2010). The HWSI (Hydrological Water Stress Index) measures the number of hundreds of people per one million m³ of available renewable water. The Social Water Scarcity Index (SWSI) equals the HWSI divided by the HDI (see Table 1) and by a correction factor of 2 (Ohlsson 2000). A SWSI or HWSI of 0 to 5 indicates sufficient water supply, a value above 5 and below 10 indicates water stress and values above 10 indicate water scarcity (see black lines). The Water Poverty Index (WPI) measures the impact of water scarcity and water provision on human populations (WRI). Its values lie between 0 and 100. High scores indicate a higher water provision. For the purpose of graphical representation the WPI has been reversed to the RWPI (Reversed Water Poverty Index) by subtracting the value for the WRI from 100. Hence, for the RWPI higher values indicate lower water provision. The categories (sufficient, stress and scarcity) only apply to the SWSI and the HWSI

Aside from the country specifics on the water supply side, all states share one common development on the demand side: significant population growth. Egypt is expected to see the strongest growth with an increase of 57 million people until 2050 (Fig. 1). Algeria and Morocco could grow by more than 14 and 10 millions, respectively. The population growth of the smaller states Libya and Tunisia is also significant, especially in relative terms. Both the relative and absolute population growth will increase the demand for food and water on the national and regional scale. Interlinked with this development are the processes of urbanization and littoralization (concentration of population along the coast) which could lead to highly localized peaks in water and food demand.

Agricultural sector

The agricultural sector is in all North African countries by far the largest consumer of water, mostly reaching values above 80% (Table 2). It is therefore promising to look into the agricultural sector and its importance for the each country in more detail.

Except from Egypt's agricultural sector which is focused on the Nile, all other countries in North Africa depend almost entirely on precipitation as the main water source for agriculture (see Table 2, Fig.1 and Fig. 4). The dependence on precipitation determines the impact of climate change on agricultural productivity. While the agricultural productivity can be increased under climate change conditions in Egypt, a decrease in productivity of almost 30% is projected for Algeria and Morocco, even if the use of carbon fertilization is considered (Cline 2007 and Table 2). Without carbon fertilization the climate change impact increases by 10% (see also Lhomme, Mougou et al. 2009; Nelson, Rosegrant et al. 2009; Requier-Desjardins 2010; Mougou, Mansour et al. 2011). The IPCC (2007) estimates that in North Africa climate change will cause a loss in agriculture of between 0.4 and 1.3% of GDP by 2100.

Table 2 Agriculture and climate change impact in North Africa (Cline 2007; FAO 2010; FAO 2010)

State	Percentage of water withdrawals used for agricultural purposes (2000)	Rain fed land as a percent of total agricultural area (2003)	Percent impact of climate change on agricultural productivity by 2080 (compared to 2003), without carbon fertilization	Percent impact of climate change on agricultural productivity by 2080 (compared to 2003), with carbon fertilization
Algeria	65	98.6	-36	-26.4
Egypt	86	0.1	11.3	28
Libya	83	97	NA	NA
Morocco	87	95.2	-39	-29.9
Tunisia	82	96	NA	NA

The importance of the agricultural sector for the economy varies strongly among the considered states. Table 3 shows the sectoral composition of GDP and labor force in North Africa. In Algeria and Libya the industry contributes most to the GDP, while in Egypt, Morocco and Tunisia the service sector is most important. Agriculture is in none of the countries the largest contributor to GDP. However, in Morocco the agricultural sector, reaching 17%, is significant for the GDP. This becomes even more evident when the occupational distribution across sectors is considered. Almost half of the working population in Morocco is employed in the agricultural sector (Table 3). Considering both GDP and employment, the importance of the agricultural sector in North Africa ranges from medium (Libya, Algeria) to high (Tunisia) and very high (Morocco, Egypt).

Table 3 Sectoral composition of GDP and labor force in North Africa (CIA 2010)

	GDP (est. 2010)			Labor force (est.)		
State	Agriculture percentage	Industry percentage	Services percentage	Agriculture percentage	Industry percentage	Services percentage
Algeria	**8.3**	61.5	30.2	**14** (2003)	13.4	NA
Egypt	**13.5**	37.9	48.6	**32** (2001)	17	51
Libya	**2.6**	63.8	33.6	**17** (2004)	23	59
Morocco	**17.1**	31.6	51.4	**44.6** (2006)	19.8	35.5
Tunisia	**10.6**	34.6	54.8	**18.3** (2009)	31.9	49.8

In summary, water is the most affected resource by climate change in North Africa. Depending on the index used, the water situation is most severe in Libya and Algeria (physical water availability) or in Morocco (water poverty index). The dependency on water and its importance for the economy is highest in Morocco, making the country overall the most sensitive to climate change.

3.2 Adaptive capacity

According to the IPCC, the adaptive capacity of a society can be divided into generic and impact specific indicators. “Generic indicators include factors such as education, income and health. Indicators specific to a particular impact, such as drought or floods, may relate to institutions, knowledge and technology” (IPCC 2007:727). Using indicators suggested by the IPCC (2007) and Adger (2006), this section compares the generic and impact specific adaptive capacities of Algeria, Egypt, Libya, Morocco and Tunisia.

Generic adaptive capacity

The generic adaptive capacity refers the capacity of a society to adapt to changes in general. Key determinants are economic resources, human development, health and education (2007). The absolute economic resources are largest in Egypt, followed by Algeria and the significantly weaker economies of Libya, Morocco and Tunisia (Table 4). When measured in per capita income as suggested by Adger (2006), the distribution of the economic power changes. Here, Libya ranks highest and Morocco lowest. For the individual adaptive capacity, it is important to consider not only the per capita income level but also its distribution among the households of a society. The highest levels of income inequality are found in Morocco and Tunisia (see Gini index in Table 4). According to the human development index Morocco shows the largest development deficit (Table 4).

Table 4 Generic indicators 1: Income and human development in North Africa (UNDP 2009)

State	GDP[1] in billion PPP[2] USD (2009 est.)	GDP per capita in PPP USD (2007)	GINI index[3] (average 1991-2007)	HDI[4] (2007)
Algeria	239.6	7740	35.3	0.754
Egypt	471.2	5329	32.1	0.703
Libya	95.88	14364	N/A	0.847
Morocco	91.84	4108	40.9	0.654
Tunisia	84.04	7520	40.8	0.769

[1] GDP: gross domestic product, [2] PPP: purchasing power parity, [3] the Gini index lies between 0 and 100. A value of 0 represents absolute equality and 100 absolute inequality. [4] HDI: Human development index

The health level of the North African countries lies above the average of the continent and below the European level. While the under-five mortality rate of Algeria and Morocco is comparably high among the considered countries, with values of 37 and 36 respectively (per 1000 live births) (Table 5), it is still low compared to the average value of 78 for the countries of the Eastern Mediterranean region (for a complete list of countries see WHO 2010:176). The life expectancy at birth is around 70 years in all North African countries (WHO 2010). Further, the percentage of undernourished population has not been critical over the past 20 years (FAO 2010). More than 90% of the rural population of the considered countries use improved drinking-water sources, except for Morocco where this share only accounts for 60% (Table 5).

Table 5 Generic indicators 2: Health and education in North Africa (UNDP 2009; WHO 2010)

State	Under-five mortality rate (2008)[1]	Percentage of rural population using improved drinking-water sources (2008)	Education index (2007)[2]
Algeria	37	97	0.748
Egypt	23	98	0.697
Libya	17	NA	0.898
Morocco	36	60	0.574
Tunisia	21	94	0.772

[1] probability of dying by age 5 per 1000 live births, [2] the education index combines adult literacy rates and gross enrolment ratios

Overall, Morocco has the lowest generic adaptive capacity in North Africa. The country performs poorest in economic resources, human development, health and education. Prior to the outbreak of the war in 2011 (see for example Economist 2011), Libya had the highest generic adaptive capacity in North Africa.

Impact specific adaptive capacity

The adaptive capacity, specific to an impact, is shaped by the performance of institutions and the availability of knowledge and technology. With respect to the performance of institutions and the region's overall development, the level of corruption has been identified as a "fundamental challenge" (Transparency International 2008). Widespread corruption limits the efficient use of economic assets (see previous section) to cope with the effects of climate change (Transparency International 2011). Within North Africa, all countries have "a serious corruption problem" (Transparency International 2008) as none of the countries reaches the threshold score of 5. The level of corruption is lowest in Morocco and Tunisia (Table 6).

Table 6 Impact specific indicators: Corruption, knowledge and technology in North Africa (Schwab 2010; Transparency International 2010; World Bank 2010)

State	Corruption perceptions index (2009) [1]	Knowledge index (2009) [2]	Technological readiness index (2010)
Algeria	2.8	3.57 *	3.0
Egypt	2.8	4.24	3.3
Libya	2.5	N/A	2.9
Morocco	3.3	3.35	3.5
Tunisia	4.2	4.54	3.9

[1] the corruption perception index measures the perceived level of public-sector corruption. It is a "survey of surveys", based on 13 different expert and business surveys [2] the knowledge index is composed out of key variables on education, innovation, and innovation and communication technology, * incomplete data

The knowledge index suggested by the World Bank "measures a country's ability to generate, adopt and diffuse knowledge" (World Bank 2009). As the index is composed out of different indicators on education, human resources, innovation, and information and communication technology, it interlinks with other impact specific and generic indicators (see previous section). Further, the index does not take indigenous knowledge into account which has been identified by several studies to be critical with respect to climate change adaptation (Folke, Hahn et al. 2005; Pedersen and Benjaminsen 2008; Ensor and Berger 2009). Still, the index allows for a general classification. In all five North African countries, the level of knowledge is lower than the Middle Eastern and North African average of 5.68 but significantly higher than the continents average of 2.72 (World Bank 2009 and Table 6).

Closely interlinked with the level of knowledge is the level of technology. Based on the Technological Readiness index, Tunisia is the most advanced country while Libya marks the lower end (Table 6). The index combines several components such as foreign direct investments, availability of latest technologies and number of internet users. As the predictive skill of seasonal forecasts is growing (Section 2), the availability of technology is particularly important to communicate information to farmers and pastoralist.

In general, the impact specific adaptive capacity of a country is more difficult to characterize than the generic adaptive capacity. This is mainly because institutions, knowledge and technology are broader categories than the ones used to define the general adaptive capacity. Fewer well-established indicators exist for the impact specific adaptive capacity. Especially the knowledge index is incomprehensive as it partially relies on incomplete data and is not available for Libya. Some conclusions can still be drawn. Tunisia scores best in all three categories (corruption, knowledge and technology). Morocco performs relatively well in terms of corruption and technology, whereas Libya shows the lowest values in these categories.

3.3 Comparison and conflict implications

In order to assess the vulnerability of a country or a region, it is necessary to discuss and visualize the three elements of vulnerability in a joint manner. Figure 5 pursues this aim, combining main indicators for the generic adaptive capacity (light grey shading) with main indicators for sensitivity (darker grey shading).[5] The figure relates the individual values of each country to the highest and lowest observed in North Africa. For reasons of graphical representation, the indicators representing the sensitivity towards climate change have been reversed to insensitivity. A greater plot area therefore indicates a higher generic adaptive capacity and a lower sensitivity.

Comparing the countries' plots, several aspects become apparent: A general weakness of the region is its high dependency on rain fed agriculture, which can be observed in all countries but Egypt. In Egypt the importance of agriculture for employment and GDP as well as the low per capita GDP are most critical. Algeria and Tunisia show a similar distribution of generic adaptive capacity and sensitivity. Their greatest strengths are the level of education and human development. These categories were best developed in Libya. Yet, Libya’s adaptive capacity has suffered considerably from the violent conflict in 2011. Morocco has the smallest plot area, showing that it is the country with the lowest generic adaptive capacity and the highest sensitivity. The country’s impact specific adaptive capacity is relatively better developed (see 3.2). However, the combination of high climate exposure, low generic adaptive capacity and high sensitivity makes Morocco the most vulnerable state in a vulnerable region.

This result is in line with Yohe et al. (2006) who apply a combined index of exposure and sensitivity to find a significant level of climate change vulnerability for Morocco and Tunisia (and a moderate level of vulnerability for the remaining countries). Sullivan and Huntingford (2009), using the climate vulnerability index (a composition of the previously discussed WPI and additional geographical factors), assess the vulnerability of the region to be medium high. Similar results are presented by Iglesias et al. (2009).

[5] The impact specific adaptive capacity is not included because of its limitations discussed in 3.2. The water situation is not shown, since it is already displayed in Figure 4.

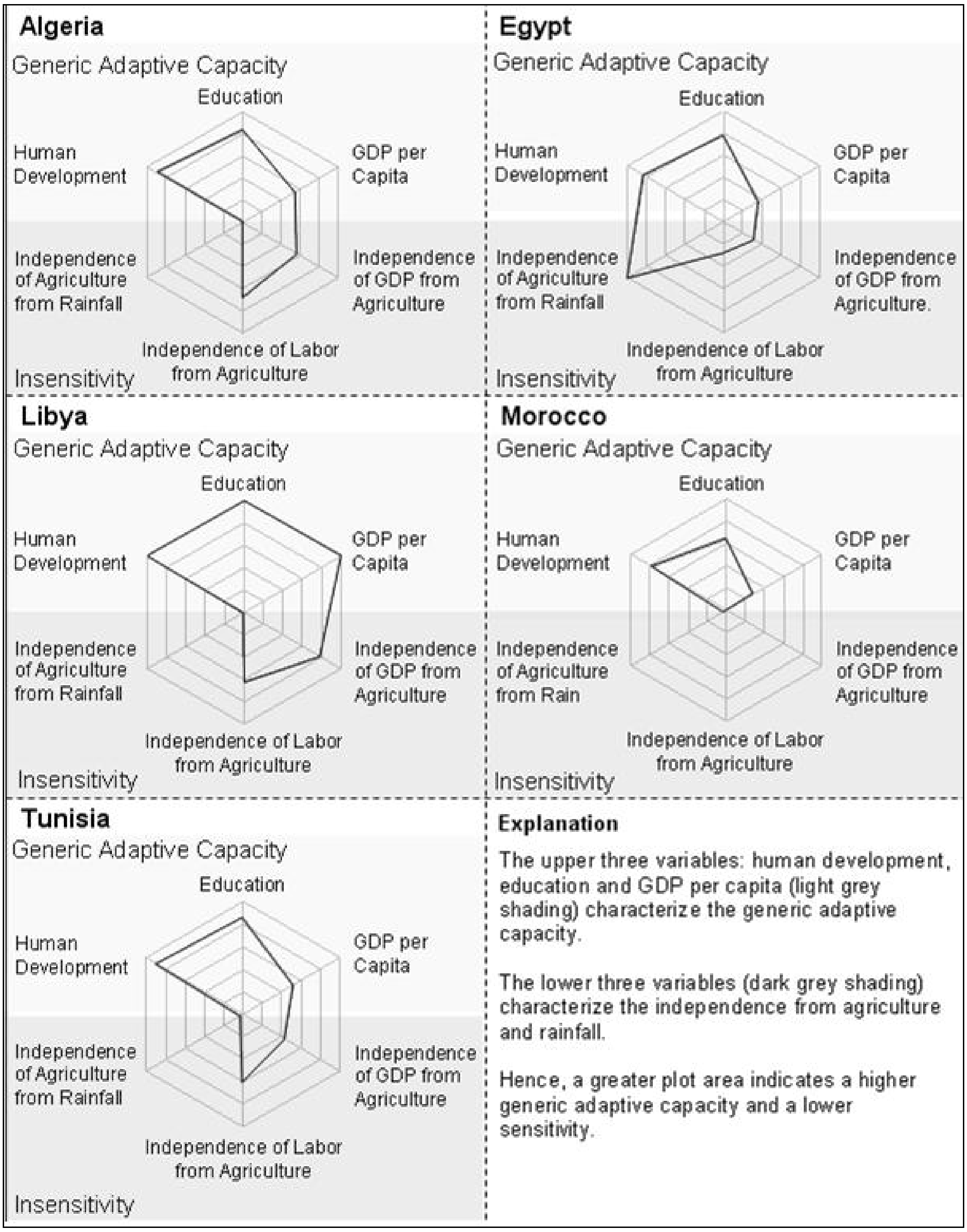

Fig. 5 Generic adaptive capacity and insensitivity to climate change in North Africa (own calculations based on UNDP 2009 see also values in Table 2 through 5; CIA 2010; FAO 2010). For the upper three variables (human development, education and GDP per capita) the highest value in North Africa is set 100 and the other country values are calculated accordingly. The lower three variables (related to agriculture) are taken from Table 2 and 3 and reversed for graphical representation

Conflict implications

Against the background of high vulnerability, increasing demand for food and water (driven by population growth) and the projected decline in agricultural productivity (driven by climate change), concerns have been raised about food and water security and its implications for conflict (Iglesias, Mougou et al. 2010; Scheffran and Battaglini 2011).[6] Iglesias et al. (2010:165) see a "potential for more pronounced water conflicts of neighbouring countries" in North Africa. Smith and Vivekananda (2007:19) find a "high risk of political instability as a knock-on consequence of climate change" for Egypt, Libya and Morocco after assessing the factors of conflict, poverty, inequality, and governance. While no risk was identified for Tunisia, "a high risk of armed conflict as a knock-on consequence of climate change" is expected for Algeria (ibid.).

Homer-Dixon's environmental scarcity theory (Homer-Dixon 1994; Homer-Dixon 1999) claims that environmental change likely leads to violent conflict when it is combined with population growth and unequal resource distribution. While our previous discussion has shown that water scarcity and population growth are characteristics of North Africa (see Fig. 1 and 3), unequal resource distribution is more difficult to capture.

Table 7 Armed conflicts in North Africa between 1998 and 2008 (PRIO 2009)

State	Number of conflicts 1989-2008	Dominant conflict intensity	Dominant conflict type
Algeria	18	minor armed conflicts and war	Internal armed conflict
Egypt	6	minor armed conflicts	Internal armed conflict
Libya	0		
Morocco	1	minor armed conflicts	Internal armed conflict
Tunisia	0		

Peace Research Institute Oslo (PRIO) uses the UCDP (Uppsala Conflict Database Program) definition of armed conflict: "a contested incompatibility that concerns government and/or territory where the use of armed force between two parties, of which at least one is the government of a state, results in at least 25 battle-related deaths" (PRIO 2009:1). An "internal armed conflict occurs between the government of a state and one or more internal opposition group(s) without intervention from other states" (ibid.). A conflict of minor intensity has between 25 and 999 battle-related deaths in a given year (PRIO 2009:7). Above this threshold a conflict is classified as "war" (ibid.)

In the context of environmental conflict theory, Morocco seems to be particularly conflict prone. Compared to the other North African countries, Morocco is also closest to meeting the criterion of low per capita income (see Table 1), which is often seen as a key factor for violent conflict (Collier, Elliott et al. 2003; Collier 2007). According to Collier (2007) countries, which have experienced violent conflicts before, face a significantly higher risk of violence, especially within a 5 year post-conflict phase. In this regard Algeria, Egypt and most recently Libya are more conflict prone as they have experienced more conflicts in the recent two decades (Table 7). The application of Homer-Dixon's and Collier's conflict framework should not be misinterpreted as a simplification of the climate-conflict complex. Indeed, there are more factors such as ethnic diversity

[6] A general introduction to the security implications of climate change can be found in Barnett and Adger (2007), Nordås and Gleditsch (2007), WBGU (2007), Brzoska (2009); Brauch (2009), Webersik (2010), Scheffran and Battaglini (2011); Scheffran et al. (2011, forthcoming). Regarding implications for Africa see Brown and Crawford (2009).

and political marginalization (for Morocco see Rössler, Kirscht et al. 2010) that potentially contribute to conflict. However, the discussion of population growth, unequal resource distribution, per capita income and conflict history is a first attempt to assess the conflict sensitivity of a country.

In general, the assessment of potential conflict implications of climate change is a difficult task since there is neither a direct measurement of the resource distribution nor of small scale violent events (which would for instance capture food riots). PRIO's definition of conflict for example requires at least 25 battle-related deaths and the state as one conflict party (see Table 7). These criteria exclude lower levels of violence as well as conflicts where the state is not directly involved.[7] Nevertheless the use of Homer-Dixon's environmental scarcity theory and Collier's conflict factors point to Morocco (unequal income distribution, high water poverty, comparatively low per capita income) and Algeria as well as Egypt (both high number of past conflicts, strong population growth) to being suitable for a more comprehensive analysis. Yet, Mougou et al. (2011) have shown that also Tunisia is promising in this regard.

To improve the understanding of the interrelations between climate change, conflict and adaptation, it is in any case necessary to leave the regional perspective and to look into one country in more detail.

4. Climate change impacts on agriculture and adaptation in Morocco

We focus in this section on Morocco because our analysis of vulnerability indicates Morocco as especially vulnerable to the effects of climate change. This focus allows us to discuss the impacts of climate change, its characteristics, developments, and socio-economic implications in more detail and with a closer look at the empirical data and policy options. Nonetheless, the conclusions drawn from this section can be related back to other North African countries to some degree, since their agricultural systems and expected climatic impacts are similar (Giannakopoulos, Le Sager et al. 2009).

4.1 Traditional land use and recent developments

The main components of the Moroccan land use sector are farming and pastoral livestock husbandry, which have evolved for centuries under spatial and temporal fluctuations in precipitation (Barrow and Hicham 2000). Farming is practised in the more fertile and humid locations, whereas pastoral livestock husbandry makes best use of marginal lands through extensive grazing of mainly sheep and goats. Traditionally, both components are combined which allows to buffer income shocks from droughts (Casciarri and Chatty 2006).

[7] Increasing attention is being paid to data bases of low-level instability events (see Nardulli and Leetaru 2010; Nardulli 2011).

Farming

To ensure resilience in rain fed agriculture, which is used on more than 90% of the Moroccan arable land (Fig. 1), special crop mixes and harvesting strategies are traditionally applied. For instance, barley is traditionally used instead of wheat, because barley needs less water and ripens faster, which increases the capability of resistance against water deficit (Kuhn, Heidecke et al. 2010). Late planting of lentils makes best use of available water after late rains, recognizing shorter temporal fluctuations in rainfall (Lybbert, Kusunose et al. 2009), whereas fallow accumulates water on a yearly-timescale on arable land. A scattering of fields tries to avoid severe shocks by taking advantage of spatial variations in precipitation. An additional buffer is built up by stockpiling grain in good years (Skees, Gober et al. 2001). In the southern part of Morocco, the traditional adaptation of farming to a semi-arid to arid climate is the extended use of surface irrigation systems (‘seguias’) in the oases. Irrigated fields are additionally surrounded by trees such as apple, walnut, almond, olives, and date palms to use the percolating water as efficient as possible. This land use in the southern regions is combined with the aforementioned adaptation strategies (Barrow and Hicham 2000; Rössler, Kirscht et al. 2010).

Since the middle of the 20th century, traditional agricultural strategies to cope with erratic and diverse precipitation patterns have changed substantially. The use of nitrogen fertilizer, mechanization, and the heavy use of irrigation (surface water and groundwater) were promoted in farming sector with the main objective of the government to increase cereal production and to expand cropland (Badraoui, Agbani et al. 2000; Davis 2006). Especially the more drought prone wheat was supported by many governmental initiatives.

The new mode of agriculture allowed to maximize the production in years with sufficient rain, while it increased potential severity of droughts in dry years. The same is also observed for other North African countries (e.g. Latiri, Lhomme et al. 2010). As Figure 6 shows, maximum yields and maximum harvested area in Morocco increased during the last 30 years, while the variability of both parameters increased as well. The agricultural model therefore can be characterized as a “higher-risk higher-stakes game” in comparison to the traditional one (Lybbert, Kusunose et al. 2009:6).

Despite a higher risk of crop failure, governmental programmes advocated this development in order to become more independent from cereal imports and to abate the exodus of people from rural areas. For instance, farmers were encouraged to declare property by ploughing former collective rangelands and establishing water pumps (Davis 2006). Additionally, the use of groundwater for irrigation is still free of any charge for the southern regions of Ouarzazate and Tafilalet (Badraoui, Agbani et al. 2000).

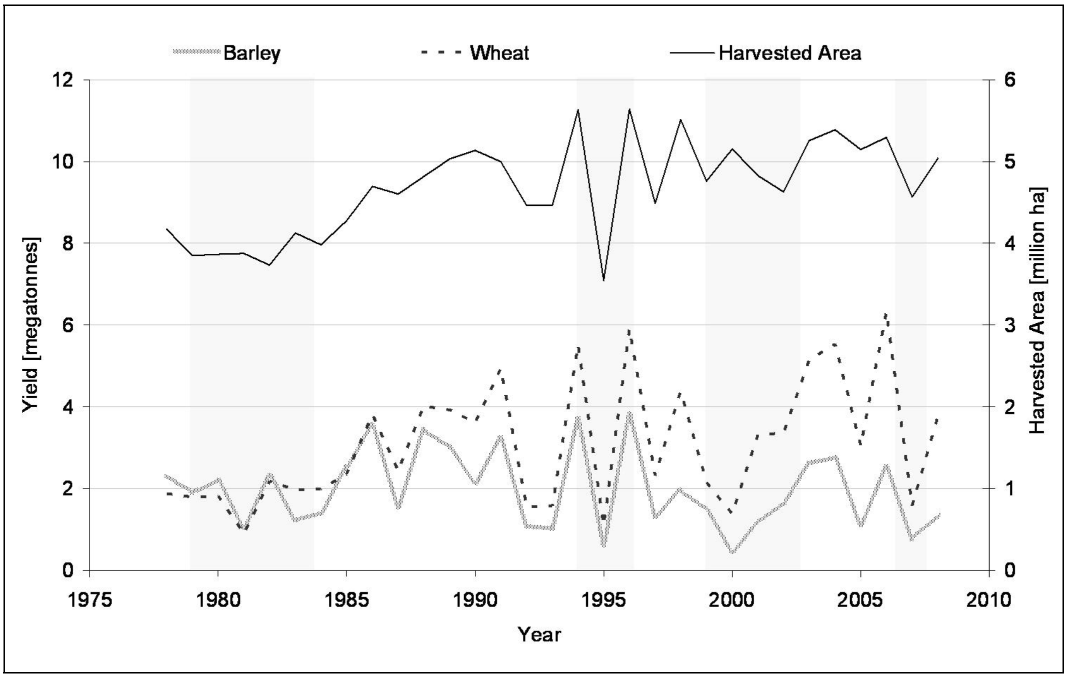

Fig. 6 Harvested area and yields of barley and wheat in Morocco from 1978 to 2008. Drought periods are indicated with grey background (own representation based on FAO 2010)

Surface-water management projects in Morocco, necessary for expansion of irrigated agriculture, relied in the past mostly on building large dams, which transferred the control over water resources from local owners to national authorities. This centralizing strategy had two effects: First, traditional water management systems were devaluated. Second, the farmers did not perceive an improved supply with irrigation water. Thus, in combination with the trend of mechanization, farmers were encouraged to switch their irrigation systems from surface water to groundwater supply, where they control the access to a varying degree themselves (Heidecke (Heidecke, Kuhn et al. 2010). This, in consequence, lead to a massive drop of groundwater tables in the past decades which in turn already lowered grain yields in some areas (Breuer and Gertel 2007; Fink, Christoph et al. 2010; Kuhn, Heidecke et al. 2010). Additionally, inadequate irrigation always implies the risk of salinization, which can be increasingly observed in Morocco, where 35% of irrigated areas can be considered as saline (Badraoui, Agbani et al. 2000). In the southern province of Ouarzazate (IMPETUS project area, see Fig. 1), even 80% of the soils are affected by salinization, 45% of them at a critical level (Davis 2006).

Livestock husbandry

Within the sector of pastoral livestock husbandry, the most dominant traditional adaptation to droughts and precipitation irregularities is the wandering of herds according to precipitation patterns (transhumance). Traditionally, animals are slaughtered during times of fodder scarcity to prevent starvation even though prices are significantly lower during such periods (Hazell, Oram et al. 2001; Skees, Gober et al. 2001). Furthermore, reciprocal grazing arrangements with distant tribes as well as social networks are used to buffer income shocks caused by droughts (Hazell, Oram et al. 2001; Kuhn, Heidecke et al. 2010). A modern way of transhumance, in order to by-pass fodder scarcity, is the usage of trucks to transport the flocks to distant areas (Breuer 2007).

From the 1960s on, the government began to establish drought relief measures in the form of fodder subsidies and the rescheduling of loans. This practice turned transhumance from a necessity into an alternative and promoted tendencies of sedentarity and urbanization. Since close relations to governmental authorities ensured fodder supply, the policy of fodder subsidies enhanced fragmentation of tribal structures, which formerly controlled access to pastures (Rachik 2007). While the interventions of the government reduced the catastrophic losses of livestock in recent droughts (see Fig. 7), this policy made it possible to keep herd sizes at a higher level since the traditional de-stocking during droughts was drastically reduced. Remittances of emigrants from Europe enabled the purchase of supplementary fodder as well (Kuhn, Heidecke et al. 2010).

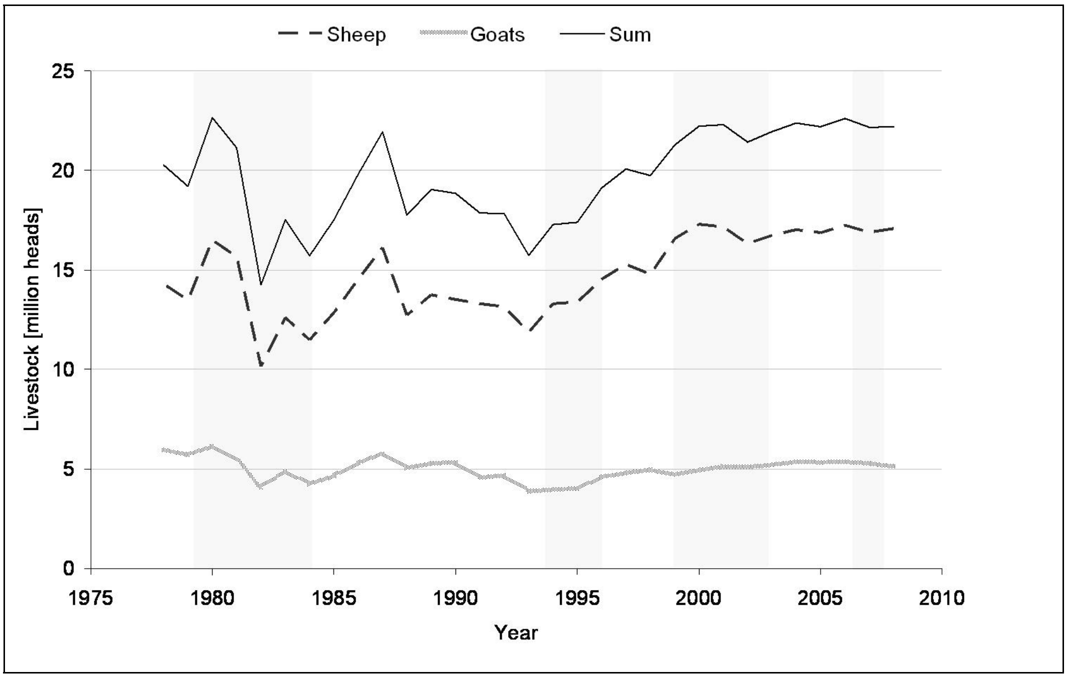

Fig. 7 Numbers of livestock (sheep and goats) in Morocco in million heads from 1978 to 2008 (own representation based on FAO 2010). Drought periods are indicated with grey background

Overall, fodder subsidies and remittances led to an increased grazing pressure in Moroccan rangelands over the past decades. Figure 7 shows the number of goats and sheep from 1978 till 2008. The numbers have to be seen in relation with the expansion of cropland which increased by about 25% since 1980 (see Fig. 6). Hence, while precipitation was decreasing, livestock density increased. Additionally, in contrast to cereal production, the volatility of livestock numbers has decreased over the past decade mainly due to the stabilizing effect of fodder subsidies.

However, degradation of rangelands in Morocco is not only caused by high stocking rates, but also because of ploughing of marginal lands and an increasing demand in firewood for cooking and heating (Le Houérou 1996; El Moudden 2004; Davis 2006). Particularly pastures with sufficient precipitation (>200 mm p.a.) and proximity to settlements are affected by this kind of degradation, since the human influence is decisive on these ecosystems (Finckh, Goldbach et al. 2010). On arid pastures, with precipitation below 200 mm, the anthropogenic influence is less pronounced, because vegetation of these ecosystems is mainly controlled by natural water scarcity (Finckh, Goldbach et al. 2010).

Besides husbandry of sheep and goats, the production of cow milk has become increasingly important, experiencing an increment in production by a factor of three within the past 30 years. Diairy farming is well integrated into small scale farming, since for instance 85% of milk producers in the southern parts of the country have less than three cows (Maroc 2008). Because income from milk production is relatively stable, it is seen as an adequate measure for poverty reduction and income diversification. That is why the new Moroccan agricultural strategy is aiming at up to a doubling of milk production till 2020 (Maroc 2008), even though dairy farming in North Africa is expected to be negatively affected by climate change (Ben Salem and Bouraoui 2009).

The traditional diversification of income sources in Morocco between farming and livestock keeping in rural households is currently developing into a "multi resource economy" (Casciarri and Chatty 2006:421). New options of livelihoods, such as engaging in wage labour, and national or international migration of household members allow a wider diversification of income sources (Rössler, Kirscht et al. 2010). In the southern province of Ouarzazate for instance (see Fig. 1), already 44% of the working population are engaged in some sort of wage labor which decreases their dependency from agriculture and promotes sedentarity (Breuer 2007). Hence, 42% of former pastoral households gave up their mobility (Rachik 2007).

Plan Maroc Vert

In 2008 the Moroccan government released a new agricultural strategy, called "Plan Maroc Vert" (PMV; Maroc 2008). Beside the objective of promoting "aggressively" (Maroc 2008) the productivity of the Moroccan agriculture, the PMV addresses as well climate change (Maroc 2011), overexploitation of groundwater reserves, and alleviation of poverty. Main feature of the strategy is a distinction of two pillars: Pillar one is aiming at promoting a "modern agriculture, competitive, with a high added value and adapted to markets" (Maroc 2008:1). Pillar two is dedicated at "combating poverty through amelioration of agricultural revenues" of small scale farmers (ibid.). The PMV is accompanied by planned investments of 12-17 Billion Euro, whereby almost 90% of investments are dedicated to pillar one (Maroc 2008).

Measures to achieve an increase in agricultural productivity within the PMV of up to 59% till 2020 are mainly: intensification of production techniques, extension of cropland, improvement of localized irrigation techniques and an improved processing of agricultural products (Maroc (Maroc 2008). Furthermore, it is discussed that the decentralization of agricultural policy and a combination of governmental interventions with traditional resource management systems is a major achievement of the PMV, too (Toumi 2008). In contrast to the previous agricultural policy, the priority is shifted from cereal production to production and processing of vegetables, citrus fruits and olives for a growing international market. For instance, the extension of crop areas and improvements in processing of olives are expected to increase the added value of olive products till 2020 by a factor of four (Maroc 2008). However, given the projections of climatic changes and their effects on agricultural productivity in North Africa (see section 3.2), it remains questionable if the ambitious goals of the PMV can be reached. Below, we will turn to the question, if the focus is set legitimately on an agriculture which is considered to serve in times of climate change as the "principle motor of national economic growth" (Maroc 2011:7).

In summary, the current development of the Moroccan agriculture can be described by “mechanization, market orientation and specialization" for the farming sector, and “maximization” for the pastoral sector if sufficient capital is available. The question has to be raised now, how effective these measures were at coping with past droughts (4.2) and what options exist for the future (4.3).

4.2 Impacts of climate change on agriculture and implications for societal stability

In this section we will discuss expected impacts from climate change in Morocco on agriculture and implications on income security, social inequality, food security, and hence, societal (in-)stability. We concentrate on the impacts on agricultural production because, as shown in section 3, it is the main component which attributes to vulnerability of Morocco to climate change. Agriculture will be threatened by soil degradation as well as altered average conditions for plant growth. An increased frequency of droughts has already shown socio-economic impacts in the past.

Soil degradation and yield losses

Soil erosion in general threatens the possibility of North African countries to adapt to climatic changes (e.g. Iglesias, Mougou et al. 2010; Requier-Desjardins 2010). Already 75% of arable lands in Morocco are affected by erosion (Maroc 2011). However, concerning projections on erosion, future land use is decisive concerning projections on erosion rates (e.g. Kosmas, Danalatos et al. 1997). As shown in section two, peak rainfall rates are not expected to increase for the north western part of Morocco. Thus, in this area, erosion rates will largely depend on land use practices. In contrast, projected extremes in daily rainfall in the Atlas Mountains will be able to increase erosion rates of fertile lands. For instance, under present-day land use, climate change would increase erosion from rangelands in southern Morocco until 2050 by 25% (Linstädter, Baumann et al. 2010). In the worst case, with more intense livestock grazing and increased firewood collection which is likely due to population pressure, erosion in this area might even increase by up to 45%. However, also a decrease of erosion by 30% is possible under the assumption of less intense livestock grazing and less firewood collection. Thus, in general, human influence on erosivity superposes the effects of altered precipitation in Morocco. Given the governmental objectives of increasing the area share of olives and citric fruits (Maroc (Maroc 2008), it is plausible that erosion rates might be decreasing in the future, since perennial crops show good properties concerning erosivity if at least a minimum of understory is allowed (Kosmas, Danalatos et al. 1997).

Shifting rainfall patterns and a reduction in average values of precipitation will lead to a decrease in average agricultural productivity in Morocco by around 30% till 2080 (see Table 2). Especially legumes and cereals will be affected by less favourable growing conditions and might experience a decrease in productivity of 40% and 15%, respectively, given climate projections for 2030 to 2060 (Giannakopoulos, Le Sager et al. 2009). Prospects of further yield increases for cereals are generally limited (Latiri, Lhomme et al. 2010).

Higher rates of evapotranspiration will increase salinization of irrigated farmlands if no adequate measures are taken to prevent a deterioration of the current situation. In the case of salinization, as in the case of soil erosion, human management is decisive for making projections. It has been shown for Morocco that within less than 20 years, irrigated soils can suffer a loss of more than 50% of their productivity through salinization (Badraoui, Soudi et al. 1998). Hence, since a big part of the Moroccan agricultural income is generated by irrigated agriculture (Badraoui, Agbani et al. 2000), the problem of salinization is critical: It is a problem on its own and it will considerably aggravate negative impacts from climate change.

Both, climatic changes as well as salinization of soils will hit hardest the poorer parts of the Moroccan population, since 57% of poor people are considering agriculture as their major income source, and even up to 75% in rural areas (Maroc 2011). Additionally, 48% of irrigated farmland is managed by small to medium-scale farms where quality of irrigation techniques is widely varying (Debbarh, Badraoui et al. 2002). However, even more severe can be the impacts of an increased frequency and intensity of droughts, which already have led to visible social unrest in the past. Therefore, we will now turn our focus to past and future impacts of droughts.

Droughts

As mentioned, droughts are a common phenomenon in Morocco.[8] Analyzing the period of 1456 to 2002, Touchan et al. (2008) find on average 16 single drought years per century. The 20th century lies above

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[8] See section 2 and also Bois (1957), Chbouki et al. (1995), Esper et al. (2007), FAO (2008) and Touchan et al. (2008).

this average with 19 single drought years (ibid.). For the time period 1912 to 1992, Swearingen (1992) gives an average interval between droughts of only three years. So far, no chronological pattern has been identified (Swearingen 1992; Skees, Gober et al. 2001). As shown in section 2, the trend of increasing temperature and mainly decreasing precipitation will increase the drought risk for Morocco in the future (see also Karrouk 2007; WBGU 2007). To assess what impacts these droughts could have on Morocco's agriculture, economy and food security, it is of interest to investigate effects of past droughts.

Morocco's most important agricultural product over the past decades has been wheat (Kamal 2008; FAO 2010). Its production is highly sensitive to climatic conditions. During the drought period of 1971 to 1975 the wheat production fell by 27% from the first to the last year of the drought. The drought also decreased the number of sheep by 22% and goats by 17% during the same period (FAO 2010). The reduction of livestock was similar in further drought periods (1979 to 1983, 1994 to 1995) but decreased after 1995 due to fodder subsidies (see Fig. 7). The wheat losses during the last decades became less dramatic from the beginning to the end of each drought period, but each drought invariably included one year of drastic reduction, and variability of yields and harvested areas is very high (see Fig. 6). Compared to the last year before a drought, wheat production declined by 51% in 1981, by 80% in 1994, by 36% in 1999, and by 50% in 2005 (Fig. 6). The most recent drought of 2007 in North Africa hit Morocco hardest, causing the wheat production to drop by 76% (compared to 2006). To compensate for the losses, the government significantly increased the import of cereals over the past decades and especially during drought years (FAO 2010). Consequently, the wheat supply per capita was not as strongly affected as the production. In general, undernourishment was not a widespread problem in Morocco as only 5% (1990 through 2002) or less (2004 through 2006) of the population have suffered from it (FAO 2010, see also section 3). Still, Morocco's vulnerability to climate change may have a certain conflict potential and/or can lead to social inequality.

There are some indications for a link between drought, food security and social instability in Morocco. In 1981 and 1984, drought "played a pivotal role" in "food-related insurrection" and "greatly exacerbated existent social and economic problems" (Swearingen 1992:408ff, see also; Brauch 2007). Seddon (1984) further points to Marrakesh, where drought "had seriously affected the availability of food and the cost of living" (Seddon 1984:11), especially for the poorest of the society (Glantz 1994). More recently, riots broke out in Morocco in early 2008 after a year of severe losses in food production (see Fig 6 and Guardian 2008). However, the drought related production losses were only one factor leading to social disruptions. High global food prices as well as national (food price) policies also played a significant role in the outbreak of violence (Swearingen 1992). Further, the violence did not destabilize Morocco nationwide but rather occurred on a more localized level. Nonetheless, regarding an increasing urbanization and strong growth in population, it is essential to improve options for adaptation to drought in order to avoid price shocks and food insecurity.

Social inequality

Contribution to social inequality can be another effect of more frequent and intense droughts. Pastoral livestock husbandry, using climate sensitive rangelands, is here a key element. In rural areas of semi-arid Morocco, pastoralism offers jobs for up to 38% of the working population, while 60% of herders own less than 60 sheep and goats (Maroc 2008). Small scale livestock keeping additionally serves in many cases as a saving asset (Lybbert, Kusunose et al. 2009). However, as Quaas et al. (2007) show theoretically, a diversification of income sources, as presently observed for Morocco, might shift the objective of larger-scale pastoral production away from risk minimization towards profit maximization. This promotes unsustainable ways of rangeland management. For Morocco, it has been shown that wealthier families rely less on natural resources, because they can afford buying fodder during droughts (Hazell, Oram et al. 2001; Kuhn, Heidecke et al. 2010). As an effect of that behavior, herd sizes are increased artificially during times of fodder scarcity (see Fig. 7). For the poorer livestock owners, the impacts of droughts will therefore very likely become more severe in the future, because the high grazing pressure on natural vegetation leaves little reserves for buffering water scarcity without subsidized or purchased fodder supply. After droughts, the herds of poorer farmers will then be more reduced in size than the herds of wealthier ones; and the latter ones are then in a position of using the resources of a recovering vegetation more efficiently (Zimmerman and Carter 2003). Therefore, poorer families might get poorer and wealthier ones more wealthy. If no social adjustment mechanisms are in place, this development is likely to aggravate income disparities and can turn into a vicious cycle (Lybbert, Kusunose et al. 2009).

4.3 Future options of adaptation

As shown, shifting precipitation patterns, more frequent and intense droughts as well as a general reduction in precipitation in Morocco have certainly the potential to contribute to income inequality, limited food security and shocks in food prices. Those are ingredients for societal instability. It is therefore important to consider pre-emptive agricultural and socio-economic policies which seriously take into account climate change and its societal implications.

Set of options: preconditions for adaptation

In general, adaptation to climate change arises by interaction of two major (groups of) agents: firstly, private actors, including associations on communal level and commercial enterprises; secondly, governmental initiatives. Figure 8 summarizes possible adaptation strategies and shows the potential influence of governmental initiatives on farming and pastoral activities.

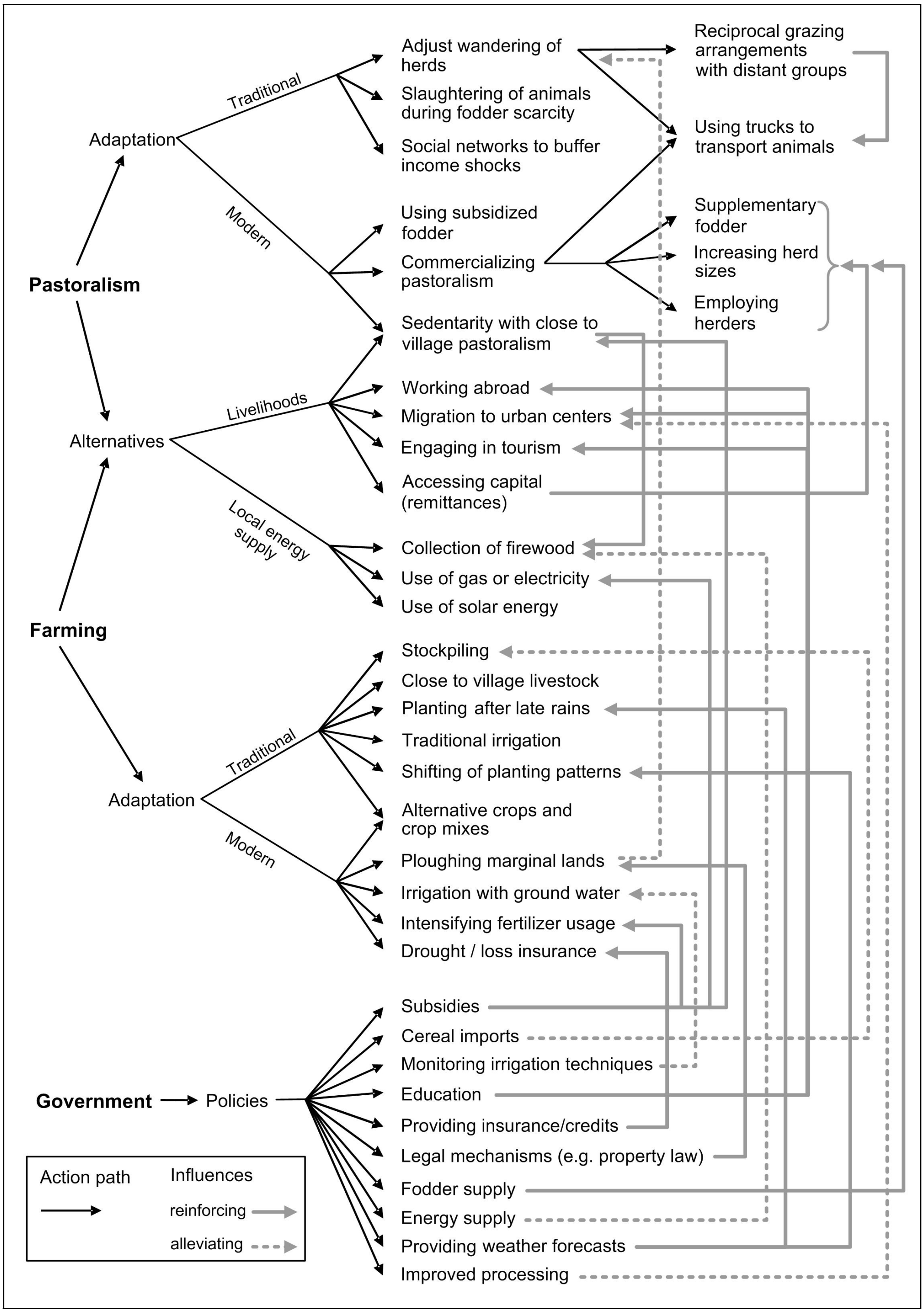

Fig. 8 Adaptation options and action paths of pastoralists, farmers and the government in Morocco (own representation)

At a first glance on figure 8, one precondition for successful adaptation to climate change can easily be seen: It is the ability, in principle, to activate the full spectrum of alternatives, which means that private entities as well as governmental initiatives are active. The new Moroccan agricultural includes this notion as "aggregation" of governmental and private initiatives (Maroc 2008). In contrast to the more centralized policies of the past, a decentralized agricultural policy is therefore legitimately considered as a key factor for a vital agriculture, in which governmental agencies recognize the small-scale farmers as most important agents (Toumi 2008). However, since the majority of small scale farmers can also be considered poor, it remains questionable why the Plan Maroc Vert (PMV) dedicates only 12% of the intended financial resources to the fight against poverty (Maroc 2008).

Another feature which becomes visible in figure 8 is that farmers and pastoralists can either adapt to climate change or switch to alternative livelihoods. However, alternative livelihoods often affect agriculture in an indirect way. For example, nomads who decide to get sedentary increase demand in firewood in the surroundings of settlements. This in turn decreases fodder availability for livestock and increases dependency on supplementary fodder. Hence, each policy needs to be sensitive to the described complexity of the actor-actor and human-environment interlinkages.

In general, adaptation strategies which are indicated with "traditional" in Figure 8 can be expected to be of less environmental impact, because these strategies evolved over hundreds of years (see section 4.1). Therefore, policies promoting traditional adaptation strategies can be regarded as "safer" concerning negative side effects. However, increasing population pressure as well as the necessities of the Moroccan economy make it inevitable to include modern adaptation strategies to sustain the functioning of the country's socio-economic system. Since these modern adaptation strategies in some cases are accompanied by critical side effects, a careful monitoring and assessment of their results is essential.

Farming

Since options for expanding irrigated areas are limited (Badraoui, Agbani et al. 2000), adaptation to projected precipitation patterns in rain fed agriculture has to arise from altered land use practices. As we showed in section two, average yearly precipitation is decreasing, but monthly precipitation is likely to increase from December to February. Thus, during the phase of highest water demand, the supply of water by precipitation and soil storage will be sufficient. For most parts of rain fed Morocco, the negative effects for cereal farming could therefore be compensated by shifted planting patterns, since early growth stages are most important for cereal yields (Latiri, Lhomme et al. 2010). However, due to the decreasing trend in precipitation for April and May, an emphasis on the traditionally used barley as dominant cereal can be recommended, since barley ripens faster than wheat.

As shown, the expansion of cropland, the increasing usage of nitrogen fertilizer, and a mechanization of agriculture were able to increase harvests in Morocco during the past. However, shocks from droughts were amplified by these new techniques (Fig. 6). Ploughing of marginal lands additionally degraded rangelands and decreased buffering capacities and the ability of transhumant pastoralists to adjust their wandering in dryer years. Concerning future prospects, the focus of agricultural production should therefore be shifted from *maximization* of outputs towards *stabilization* of outputs. This would have three effects: First, the year to year variation in agricultural outputs would decrease, which in turn increases efficiency of processing of agricultural goods because of the possibility to utilize capacities more continuously. Second, traditional adaptation strategies of the livestock sector would be strengthened. Third, even though prices of agricultural goods would be higher in good years due to lower domestic supply (which might even stimulate other adaptation mechanisms), production losses in years of drought would be reduced by producing on qualitative good soils with low salinity, and by using groundwater capacities primarily to buffer years of drought. In this way, price shocks and dependency from international food markets during droughts would be reduced. The latter point is especially interesting, because, as shown in the previous section, food riots are decisively influenced by international food prices. Independency from international food markets in years with limited rain is therefore a measure of reducing conflict potential caused by climate change.

Within a shift from maximization to stabilization, much more emphasis should be given to the problem of salinization: A higher present-day output of soils under irrigation might come at a high price of severe losses of production in the future if inadequate techniques are used (Badraoui, Soudi et al. 1998). Salinization has the potential of strongly amplifying impacts of climate change. Therefore, as already suggested for Morocco (Debbarh, Badraoui et al. 2002) and as partly done by countries like Egypt or Pakistan (Smedema and Shiati 2002), every irrigation project should be accompanied by measures to ensure leaching and drainage of the soils, as well as a monitoring of mobilized salts and their effects on other components of the hydrological system. Such a monitoring system could in turn also improve management of groundwater resources (see Fig. 8).

At the producers' side of agricultural products, area-based rainfall insurances offer the option to buffer income shocks during droughts. In contrast to subsidies, which can show many negative side effects, rainfall insurances could improve the resilience against droughts through financial means without interfering significantly with the actual land use strategies (Hazell, Oram et al. 2001; Skees, Gober et al. 2001). In Morocco, a rainfall insurance programme of the World Bank failed in the 1990s because of a continuing non-stationary downward trend in precipitation (Lybbert, Galarza et al. 2009). However, governmental support of the private sector in order to establish innovative insurance schemes could be a promising complement to technical options of adaptation.

For Morocco there is a certain potential in seasonal weather forecasting (see section two). Substantial losses of investments due to crop failure in rain fed areas could therefore be prevented in the future. Furthermore, even yield increases in good years could be achieved by using seasonal weather forecasts: In more drought prone areas farmers often hesitate to apply adequate amounts of fertilizers in order to minimize losses from low returns of investments in dry years (Latiri, Lhomme et al. 2010). Given a sufficient precise weather information in the future, it might be of interest for those farmers to apply adequate amounts of fertilizers in order to achieve higher returns.

For oases in southern Morocco, agricultural income is likely to be 17% to 30% less in 2020 than the average of 1972-2000, even though groundwater consumption is likely to double (Kuhn, Heidecke et al. 2010). A different pattern of water usage or groundwater pricing has been identified as a measure to abate these losses. However, both options face several problems concerning administrative, social and equity issues (Kuhn et al. 2010). One focus of the new Moroccan agricultural strategy lies therefore on improving the processing of agricultural primary products (Maroc 2008). It has been shown that the net monetary return from irrigated agriculture is comparably low with about 0.2 Euro per cubic meter water in Morocco, which indicates potential for improvements (Badraoui, Agbani et al. 2000; Maroc 2008). For instance, since presently products from olives show a considerable range of net returns, there can be expected an increment just by improving the processing (Maroc 2008). Since processing facilities for agricultural products offer additionally the option to create labour opportunities in rural areas, it might as well reduce the incentive for educated people to migrate to urban areas and slow down the rate of urbanization (see Fig. 8).

Pastoralism

Given the dependence on socio-economic boundary conditions such as firewood collection, the development of the pastoral livestock sector in Morocco is hardly predictable. If precipitation will become too scarce in order to pursue pastoralism, 38% to 50% of transhumant pastoralists in the south indicate to give up transhumance and opt for sedentarity as the main alternative option (Freier, Brüggemann et al. 2011). However, sedentarity with irrigated agriculture as alternative will put further pressure on groundwater resources and arable lands (Kirscht 2008). In order to activate other livelihood alternatives instead of sedentarity, such as working abroad or engaging in tourism, it can be shown that a better access to capital as well as education are prerequisites in this highly unpredictable setting (Freier (Freier, Brüggemann et al. 2011; see also Fig. 8). Investments in education can therefore be regarded as an option to adapt to climate change without considering agricultural techniques as a major controlling element.

In the past, many governmental options which have been used in the pastoral sector with respect to drought mitigation risk "achieving little more than postponing disaster and […] interfering with indigenous recovery systems" (Blench and Marriage 1999:20). In contrast, traditional property rights have managed rangeland ecosystems mostly in a sustainable way by incorporating local ecological knowledge over long periods of time. This fact rarely has been appreciated by governmental institutions (Smith 2005; Davis 2006; Linstädter, Baumann et al. 2010) and is certainly worth more emphasizing. Re-arranging traditional management systems whilst preserving their traditional core is therefore an option to increase resilience of pastoral livelihoods.

A more recent innovation in the pastoral sector, which offers a further option for adaptation, is commercial pastoralism. Increased herd sizes, trading of animals for supplementary fodder, employing additional herders, and using trucks to move herds to adequate pastures is typical for this new mode of pastoralism ("truck transhumance"; Breuer 2007). It allows livestock owners getting less dependent of price fluctuations and variability of weather. For many pastoralists, commercial pastoralism is seen as an attractive alternative. However, having sufficient capital (livestock or financial) is again a pre-condition for this alternative (Freier, Brüggemann et al. 2011). Hence, this points to a further problem of social inequality, because it shows that wealthier pastoralists have more options to adapt to climate change than poorer ones.

Truck transhumance, additionally can cause social conflicts, for example over the access and property rights of distant pastures (Breuer 2007). Further, commercial pastoralism promotes insufficient destocking during droughts and high stocking rates if local and non-local herds coincide. This in turn can easily lead to degradation of rangelands. It is therefore important that innovations emerging from the private sector which have the potential to abate impacts from climate change, such as commercial pastoralism, are scrutinized on possible negative side effects. Regulation of these side effects can then be addressed from communal or governmental institutions.

Rural energy supply

An interesting option for adaptation to climate change arises from the plan of the Moroccan government to install solar power plants with a capacity of 2000 megawatt till 2020 (Maroc 2010). The envisioned project thereby offers the option to combine a stimulus for economic development in semi-arid rural areas with the possibility of replacing firewood demand by solar powered electricity.

In Morocco, the majority of energy demand in rural areas is currently satisfied through firewood (El Moudden 2004). This is putting significant pressure on vegetation and reduces buffering capacities towards droughts and climate change. Using a bio-economic model of pastoral livestock husbandry, we investigated the potential of replacing firewood collection from rangelands in order to increase buffering capacities of the vegetation. The model was parameterized for a village located in the Ouarzazate province south of the High Atlas Mountains using sedentary livestock. The pastures of the village are situated at an altitude of 1900 meters and have an average precipitation of 270 mm per year (see Fig. 1 for exact location). A detailed description of the model can be found in Freier et al. (2011). We simulated reductions in precipitation as projected for the 21st century, and left it to the model to arrange grazing intensities. The model used the objective of optimizing revenues with planning horizons of two and five years, and with perfect foresight (indicated as "optimal" in Fig. 9). Additionally, we investigated a scenario, where we assumed an alternative energy supply and thus disabled collection of firewood from rangelands.

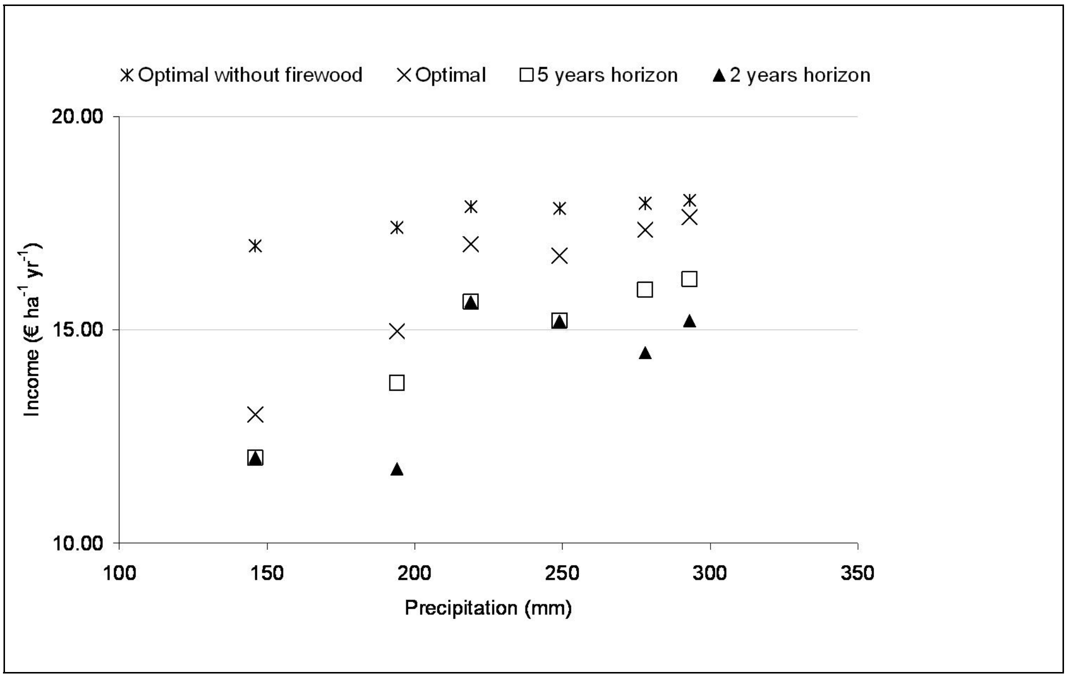

Fig. 9 Income from livestock husbandry without transhumance (own calculations). Different optimization horizons were used. Optimal: land users have perfect foresight and maximize their profits over 20-years; Five and two years horizons: land users optimize only with respect to the given time horizon (myopic behavior); Without firewood: energy demand for cooking and heating is covered by other sources than firewood from rangelands

The results of the simulations (Fig. 9) clearly show the significant potential of compensating impacts of climate change on rangelands by replacing firewood as traditional energy source. Even under a scenario with a reduction of precipitation by 45% (less than 150 mm in Fig. 9), revenues from pastoral livestock husbandry without firewood collection are still higher than present-day values with firewood collection. Thus, replacing rural energy supply is legitimately considered since long as a promising remedy to increase resilience and agricultural productivity of semi-arid to arid rangelands (Le Houérou 1996).

In the Ouarzazate province, rural households represent around 300 000 people with an energy consumption of about 140 MW (El Moudden (El Moudden 2004; Maroc 2008). A 500 megawatt solar power plant, as presently under construction in the Ouarzazate province (Bakkoury 2010), could easily satisfy the energy demand for cooking and heating of these households, if sufficient network capacities are provided. The initiative of creating the Moroccan Agency for Solar Energy (MASEN) in 2010 (Maroc 2010) is therefore not only promising from an economic perspective, but it has as well the potential to contribute to adaptation to climate change by reducing human pressure on natural rangelands.

5. Synthesis

After having addressed climatic changes and vulnerability in North Africa, as well as impacts and adaptation options for agriculture in Morocco, we are now able to summarize our findings and to conclude our assessment.

5.1 Summary

The trend of increasing annual mean temperatures that has been observed for the second half of the 20th century in North Africa is likely to continue and to cause warmer and drier conditions. Temperatures are likely to rise between 2 and 3°C while precipitation is likely to decrease between 10% and 20% until the year 2050 under the SRES A1B scenario. North-western Africa could experience a very strong warming of up to 6°C in the 21st century. Although, projections of future climate change for Africa exhibit considerable uncertainties (including the possibility of the greening of the Sahara), both the risk and the duration of droughts are likely to increase in Northern Africa.

Water scarcity (highest in Libya and Algeria) and the dependency on rain fed agriculture (highest in Morocco) contribute to the sensitivity of the region. The sensitivity is increased by population growth which is strongest in Egypt. The adaptive capacities of the North African states are lower than in Europe but higher compared to the average of the African continent. Low per capita income and its unequal distribution (most unequal in Morocco and Tunisia) limit the generic adaptive capacity while the high level of corruption is a general weakness of the impact specific adaptive capacity. In summary, climate change exposure, pronounced sensitivity and limited adaptation capacities make the region and Morocco in particular, vulnerable to climate change. Concerns that the vulnerability to climate change could contribute to social instability are reasonable. Despite the political and social changes of 2011, our analysis of conflict implications find Algeria, Egypt and Morocco to be most prone to climate change related instability.

In Morocco, the social stability has already been affected by past droughts. Climate change is likely to cause a decrease in primary agricultural production in the 21st century in Morocco of 15% to 40%. Future droughts additionally have the potential to increase social inequality, and threaten social stability by severe shocks in food prices. Both, reduction in productivity and impact of drought will be strongly aggravated by soil degradation, mainly due to salinization if the current development is projected into the future.

The incentives used in the past to increase the agricultural production in Morocco are inadequate to buffer effects of droughts, especially for the poorer part of the population which still depends largely on income from agriculture. On the contrary, some recent developments like cropping of marginal lands, depletion of groundwater resources, and the growing of wheat instead of the traditionally used barley are likely to increase the vulnerability of the agricultural sector to climate change.

The new agricultural strategy of Morocco "Plan Maroc Vert" addresses some of these issues as it builds on two pillars: output maximization for industrial agriculture and the fight against poverty for small-scale agriculture. The emphasis on increasing the added value of agricultural products such as from olives indicates a shift in policy, which has additionally the potential to reduce the rate of urbanization by creating job opportunities in rural areas. However, agriculture is still seen as a major motor of the future Moroccan economy which bears the risk of increasing present-day output while sacrificing future durability.

Analyzing policy options for adaptation we find a great variety. In general, it can be recommended to switch the focus of agricultural production from output maximization to output stabilization. For rain fed agriculture, the shifting of planting patterns and adjusting of planted crops is able to reduce impacts of climate change substantially, but a monitoring of irrigation practices and soil conditions will be crucial to secure future productivity. Area based rainfall insurances as well as a future improvement of seasonal weather predictions are further options to reduce vulnerability.

Since poorer parts of the population have less options of adaptation and will be affected more heavily, agricultural interventions should be accompanied by measures which balance social inequalities. This will contribute to social stability.

A commercialization of pastoral livestock husbandry can be recommended if it is closely linked to an empowering of traditional management institutions. Additionally, our bio-economic model shows that a replacement of firewood by electric energy supply is able to over-compensate the impacts of climate change on semi-arid rangelands. Pushing forward the development of solar power plants in arid areas, as envisioned by the Moroccan government, is therefore promising because it combines a stimulus for the domestic economy with the adaptation to climate change.

5.2 Conclusions

The significant challenges posed by climate change increase the importance of adaptation in North Africa. Adaptation measures have to address the specific elements of exposure and sensitivity to efficiently reduce vulnerability. Further, adaptation to climate change can not be achieved by one sector alone.

For the agricultural sector, strategies are most promising which focus on conservation of productive assets instead of depleting them to maximize present day output. A mismanagement of soil quality, rangeland vegetation, and groundwater extraction will have severe consequences in the future since it amplifies the impacts of climate change.

There are many options for adaptation to climate change available in agriculture. In the past, traditional options have been considerably altered and partly devaluated in the course of a restructuring of institutional regulation. In order to take advantage of the full spectrum of technological innovations such as localized irrigation and commercial pastoralism, it is necessary to have strong monitoring mechanisms to ensure a sustainable application. The efficiency of the monitoring mechanisms depends on the degree to which they include local and specific knowledge. This suggests a decentralization of structures.

Failure to implement policies which address both, agriculture specific needs and socio-economic developments, considerably increases the risk that climate change contributes to social inequality and instability in North Africa.

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