Climate change adaptation and sustainable regional development: A case study for the Federal State of Brandenburg, Germany

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1. Abstract

Located in a relatively dry region and characterized by mainly sandy soils, the German Federal State of Brandenburg (surrounding the capital city of Berlin) is especially vulnerable to climate change impacts (e.g. summer droughts) and cascading effects on ecological systems (e.g. decreasing ground water tables, water stress, fire risk, productivity losses) with socioeconomic implications. Furthermore, a complex interplay of unemployment, rural exodus, and an aging population challenges this structurally weak region. We discuss adaptation measures that are either implemented or planned, as well as research into adaptation strategies to climate change for the sectors forestry, agriculture, and water management as well as in nature conservation in the light of socioeconomic and ecological challenges and benefits. In doing so, we adopt a systemic view of Brandenburg where the sectors discussed are seen as subsystems embedded in a larger regional system. This at least partially holarchical approach enables the identification of conflicts between adaptation measures, but also of synergies among the sectors that pertain to successful adaptation to climate change. The insights gained ultimately highlight the need for cross-sectoral, adaptive management practices that jointly target a sustainable regional development.

Keywords: Adaptation, Brandenburg, Climate change, social-ecological systems, sustainable regional development

2. Introduction

Past greenhouse gas emissions and the inertia of the climate system lead to a temporal mismatch between the effects of mitigation and already occurring impacts of climate change (Pielke et al. 2007). Additionally, current mitigation pledges would not limit warming to less than 3°C while the amount of funding made available for adaptation covers climate change impacts up to only 1.5°C of warming (Parry 2010). Although such a general number for global adaptation can only be a rough approximation and refers only to the financial dimension of adaption, it illustrates a large ‘adaptation gap’. The currently observed and projected impacts of climate change (Füssel 2009; Smith et al. 2009), their combination, and their connection with other stressors of global change may exceed the current adaptive capacity of individual sectors (Adger and Barnett 2009). Furthermore, societies are increasingly vulnerable to climate change impacts for other reasons than climate change such as rapid coastal population growth (Pielke et al. 2007). Thus, adaptation to climate change is an urgent need and increasingly important in climate policy (Beck 2010).

In contrast to climate change mitigation which is intrinsically linked to the last 20 years’ climate policy and which is a global process, adaptation to changing environmental conditions, has always been part of human development and tailored to local or regional conditions depending of the scale of the impacts (Klein et al. 2005; Adger et al. 2007;

Dovers 2009; Olmstead and Rhode 2010). Consequently, adaptation to extreme events (e.g. floods or droughts) has been considered more important than coping with long-term changes in average climatic conditions (Adger et al. 2007; Berrang-Ford et al. 2010). However, opinions on whether ‘policy windows’ induced by extreme events constrain or facilitate adaptation diverge (Adger et al. 2007).

Despite an increasing body of scientific literature on adaptation (Arnell 2010), documentations of explicit climate change adaptation actions in human systems are rare (Berrang-Ford et al. 2010). It is evident, however, that high adaptive capacity does not necessarily translate into action (Adger and Vincent 2005; Adger et al. 2007) and even forestry projects for climate change mitigation (i.e. planting trees to ‘remove carbon from the atmosphere’) seldom consider adaptation to climate change in their management plans (Reyer et al. 2009) despite their necessarily longer-term outlook. This lack of documentation is striking, particularly since many possible climate change adaptation actions can be justified for other reasons than climate change (Adger et al. 2007; Dovers 2009): Related to forest adaptation, this could be a diversification of forest species and structures to improve stability, biodiversity, and attractiveness for visitors (Knoke et al. 2008).

Each field is developing ways to adapt to global (climate) change (e.g. see Spittlehouse and Stewart (2003) or Seppälä (2009) for forestry or Hannah et al. (2002) or Lawler (2009) for nature conservation). Adaptive capacity is not equally distributed within societies (Adger et al. 2007), and stakeholders such as companies and corporations as well as public households which are potentially impacted by climate change need to develop appropriate adaptation measures. How adaptation strategies will be developed and implemented on regional and local levels is still being discussed controversially. The participation of stakeholders in the development of such strategies has been emphasized in many publications (e.g. Dessai and Hulme 2004; Füssel 2007). Methods for engaging various stakeholder groups in climate adaptation have been tested in dialogue exercises on sectoral adaptation (Hoffmann et al. 2011). Moreover, for adapting forests to climate change, for example, Bolte et al. (2009) suggested an integrative concept of adaptive forest management which addresses different scales: Species/provenance suitability assessments to be conducted at an *international scale* covering the distribution ranges of

native and non-native species and their provenances. Priority mapping of adaptation strategies and respective decisions on where to intervene first on the *national or regional scale*. At the *local scale*, forest practitioners are finally responsible for the implementation of specific on-ground adaptation measures.
Moreover, adaptation measures in individual sectors may conflict with adaptations in other sectors and/or may entail direct or indirect social and environmental problems in other sectors or areas (Adger et al. 2007). Similarly to situations where current management practices exacerbate climate change impacts (Hulme 2005), Turner et al. (2010) point out that adaptation by humans may be a greater threat to natural systems than climate change itself. Theoretical approaches to adaptation thus call for concerted, cross-sectoral and multidisciplinary adaptation strategies that fit into a broader framework of sustainable development and regional values and that address the entire cascade of climate change impacts from the climate to social systems to avoid maladaptation (Burton et al. 2002; Adger and Barnett, 2009; Barnett 2010).

We explore these considerations for the example of the Federal State of Brandenburg in Germany, which is suitable because it is situated in a vulnerable position close to an ecotone with projected climate shifts exacerbating current problems and it surrounds Germany's capital city of Berlin. Detailed regional studies show that climatic conditions that were exceptional in the past will become more common in the future (see section 5). Environmental problems, however, also have a socioeconomic dimension (e.g. the impact of demographic changes on land-use changes); climate change can be seen as a potential social and political crisis (Leggewie and Welzer 2009). Our planet is seeing multiple major processes of change (Kunstler 2005). It is important to be aware of the complex synergies and non-linear changes both in environmental and social systems (or socio-ecological systems) and "multiple stresses in social systems can lead to runaway political chain-reactions" (Ibisch and Hobson 2010) if the changes are severe and transgress adaptive possibilities. Such considerations can be applied to larger political entities as well as to regions. The future of a region like Brandenburg is not only shaped by climatic changes but also by the developing social and economic changes at regional, national and global scales. For instance, Brandenburg's development perspectives also depend on the outcomes of the globally arising transformations in the energy and food production systems. Potentially rising prices as well as financial and economic crises caused in other sectors could cause decreasing availability of public funding and will potentially be ever more relevant drivers of regional policy.

The ultimate aim of adaptation research in Brandenburg is to answer the following question: What are the appropriate strategies for adapting Brandenburg to the various and partly uncertain impacts of complexly related global changes? The objective of this review is to discuss both implemented and planned adaptation measures as well as research into adaptation strategies to climate change in Brandenburg in the light of the socioeconomic and ecological challenges and benefits associated with them.

Although adaptation pertains to many fields and parts of society (Klein et al. 2005) we focus on land and water resources and in particular the three sectors forestry, agriculture, and water management as well as on nature conservation, which takes place in all the aforementioned sectors. We do not explicitly consider adaptation of infrastructure, the transport, energy or health and security sector. We follow the adaptation framework developed by Burton et al. (2002) insofar as we account for past and future trends in both climatic and socioeconomic development.

After briefly defining the main terms and introducing a simple conceptual model, we introduce the Brandenburg region especially in light of demographic and climatic changes. We then line up the challenges, existing as well as planned and currently discussed approaches to adaptation, and recommendations and options for action in forestry, agriculture, water management and nature conservation. We then highlight conflicts and synergies between them and integrate these in the “Brandenburg system”. Finally, we derive implications for sustainable development of the region as well as general conclusions.

3. Definitions

To apply these considerations, we rely on the following definitions which follow those of the IPCC (IPCC 2007) if not indicated otherwise. *Adaptation* is “the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (IPCC 2007). Systemically, adaptation means small scale shifts that result in the emergence of meta-states that are new operating points; under extreme conditions this shift can induce dramatic changes to systems' complexity, functions and characteristics (Hobson and Ibisch 2010). From this perspective, there can be even an adaptive simplification and degradation of systems. However, sustainable development in a changing environment implies that ecological and (dependent) social systems shift to new operating points without dramatically and abruptly changing functionality and characteristics (Ibisch 2010; Hobson and Ibisch 2010). Adaptation can be proactive (i.e. anticipatory) in character, autonomous (i.e. spontaneous without "conscious response to climatic stimuli but triggered by ecological changes in natural systems and by market or welfare changes in human systems"), or planned through "deliberate policy decision" (IPCC 2007). We do not limit our analysis to specific classes (autonomous, planned reactive…) or categories of adaptation measures (such as technological, economic etc., see Adger et al. 2009) but to those which are relevant in Brandenburg across these classes and categories. Furthermore, *sensitivity* describes "the degree to which a system is affected, either adversely or beneficially by climate variability or change", whereas *adaptive capacity* is the "ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities or to cope with the consequences" (IPCC 2007). Adaptive capacity is a function of financial means, education, infrastructure, social capital, etc. Having adaptive capacity does not necessarily mean that this capacity is used. *Vulnerability*, however, is "the degree to which the system is susceptible to, and unable to cope with, adverse effects of climate change" (IPCC 2007). *Resilience* describes the "ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organization, and the capacity to adapt to stress and change" (IPCC 2007). Despite these clear definitions, these concepts are in reality interrelated, context-specific and differ in time and space, as well as between social groups (Smit and Wandel 2006). Finally, *adaptive management* aims at preserving and developing the functionality of a system while continually monitoring and evaluating the success of management measures (Gunderson and Holling 2002).

4. Conceptual model for analyzing adaptation measures

While there have been many efforts to classify adaptation measures (e.g. Smithers and Smit 1997; Smit et al. 1999; see discussion by Eastaugh et al. 2009)), theoretical frameworks to study synergizing and conflicting effects of adaptation measures in between sectors as well as interactions between adaptation measures have only been tackled marginally (e.g. in Füssel 2007; Moser and Ekstrom 2010). To organize our examples of adaptation measures as well as their effects and linkages and to foster therewith the transfer and generalization of our outcomes, we constructed a simple conceptual model (Fig. 1). Figure 1 now shows all possible interactions: 1) A positive influence, i.e. the adaptation measure enhances the ecological, economic, or social conditions of a sector. 2) A negative side-effect, i.e. the adaptation measure deteriorates the ecological, economic, or social conditions of a sector. 3) A positive side-effect, i.e. the adaptation measure enhances the ecological, economic, or social conditions of a sector. While 1) is usually the ‘wanted’ effect of an adaptation measure, the interaction of 1) and 2) and 1) and 3) results in a conflict or a synergy respectively. These can either be inter-sectoral if different sectors are affected but also intra-sectoral if for example the adaptation measures enhances the economic but deteriorates (or enhances in case of a synergy) the ecological conditions within one sector. It is important to note that the weight of the positive and negative effects may not be equal. Thus conflicts may cover a broad range of interactions from ‘low-regret’ (Wilby and Dessai 2010) to severe conflicts, where the negative side-effect maybe much stronger than the expected positive effect. Similarly the strength of a synergy varies. Finally, Fig. 1 also shows that there maybe positive of negative interactions between two distinct adaptation measures. Throughout this document, we refer (explicitly or implicitly) to this conceptual framework to structure the examples of conflicts and synergies of adaptation measures.

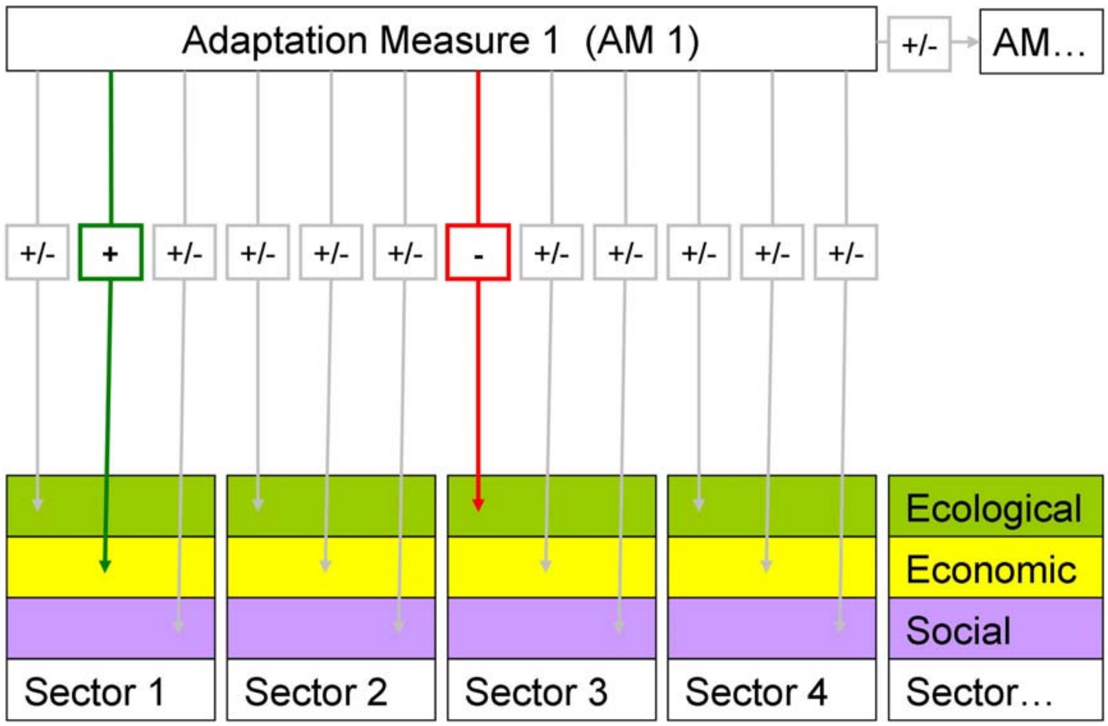

Fig. 1 Conceptual model of conflicts and synergies of adaptation measures. The arrows depict possible positive or negative effects an adaptation measure may have on ecological, economic or social aspects of a sector. In the figure, the particular example of adaptation measure 1 having a positive effect on economic aspects of sector 1 (i.e. the 'wanted effect') while having a negative effect on ecological aspects of sector 3 highlights a conflict. For a description of other possible interactions see the text.

5. Brandenburg's past and possible future socioeconomic and climatic development

Brandenburg is the fourth largest German federal state (29 481 km^2), located in the geographic region "Northeastern German Lowlands", and encircling Berlin (ASBBB 2009). Its landscape and soil formation result from several glaciations during past ice-ages and is characterized by sandy and poor soils (Büchner and Franzke 2009). Half of the total area is nowadays agricultural land (Fig. 2e)) with 10% of it being used for organic farming, Brandenburg, in comparison to the other Federal States, maintains the highest share of this land-use type in Germany (Statistisches Bundesamt 2010; ASBBB 2009). The forest area of Brandenburg (including Berlin) is 35.3%, which is more than the German average of 31% (BMELV 2006) and consists mostly of stands dominated by coniferous trees (Fig. 2e)). Whereas biomass for bioenergy generation from forests does not constitute an important part of forest production and is likely to decline in the future, bioenergy generation with biomass from short rotation coppice and agriculture is likely to increase (MUGV 2010). More than 40% of the total area is under a varying degree of nature protection (ASBBB 2009; Fig. 2d)). The population density reflects the rural character of Brandenburg: With a population density of 86 inhabitants/km^2 it is the second-last populated federal state (c.f. German average 230 inhabitants/km^2) and in the last years a rural exodus of young people and declining birth rates combined with increasing life expectancy led to a decreasing and rapidly aging population (ASBBB 2009; Fig. 2f)). The worsening economic situation in the late 90s after a brief post-reunification increase in salaries and GDP (Büchner and Franzke 2009; Baten and Böhm 2010) and the about 63% higher unemployment rate than the German average rates for the period 1994-2009 (Bundesagentur für Arbeit 2009) explain these demographic trends to a large extent (Büchner and Franzke 2009). The demographic development will strongly influence the future of Brandenburg (Büchner and Franzke 2009). Although the number of employees in the primary sector (forestry, agriculture, and fisheries) has strongly decreased in the last 20 years, this sector is still a quite important employer in Brandenburg in comparison with the German average (4% in BB versus 2% in Germany; ASBBB 2009). A special feature is the location of the German capital Berlin with 3.5 Million inhabitants in the centre of the federal state. Brandenburg provides a surrounding landscape for Berlin for recreation, ecosystem services and transport.

On top of the described changes and their repercussions, the following climatic changes have been observed and projected in this already warm and dry state (Fig. 2a/b)). Wechsung et al. (2008) analyzed climate change in Brandenburg. The analysis of the observed climate from 1951 till 2003 in Brandenburg states an increase of the annual mean temperature varying between 0.6 and 1.4 K, with annual averages for this period varying from 7.8 to 9.5°C. This trend of temperature increase is noticeably higher than the global mean temperature trend. Furthermore, Brandenburg is characterized by low annual precipitation sums compared with other German regions, on average clearly below 600 mm during the last 50 years. The trend for the period 1951-2003 is statistically not significant; there are regions in Brandenburg with decreasing annual precipitation sum and others with increasing precipitation sum. However, the seasonality of precipitation is changing towards decreasing precipitation sums during summer and increasing precipitation sums during winter. Furthermore, annual soil water shows a decreasing trend for the period 1955-2003 (Holsten et al. 2009; Fig. 2c)).

Various studies analyzed regional impacts of projected global climate change in the 21st century in Brandenburg (Gerstengarbe et al. 2003; Wechsung et al. 2008; Linke et al. 2010; Linke and Stanislawsky 2010). These studies used climate change projections from Global Circulation Models (GCM) driven with scenarios published by the IPCC (2001), especially the A1B CO_2-emission scenario. Global climate change scenarios were regionalized using statistical regional climate models (STAR (Orlowsky et al. 2008) and WettReg) or dynamic regional circulation models (CCLM, REMO) (Linke et al. 2010). It is important to note that each of these models has their own limitations which are relevant for impact studies and consequently also for adaptation planning (see review by Fowler et al. 2007). Applying the A1B scenario, simulated with the GCM ECHAM4 or ECHAM5, these studies project a temperature increase of 1-2 K in Brandenburg until 2050-2060. The regional model projections indicate a continuing decrease of precipitation sum during summer and an increase during winter. A decline of the climatic water balance could be the consequence of the temperature and the precipitation trends yielding negative values during the vegetation period.

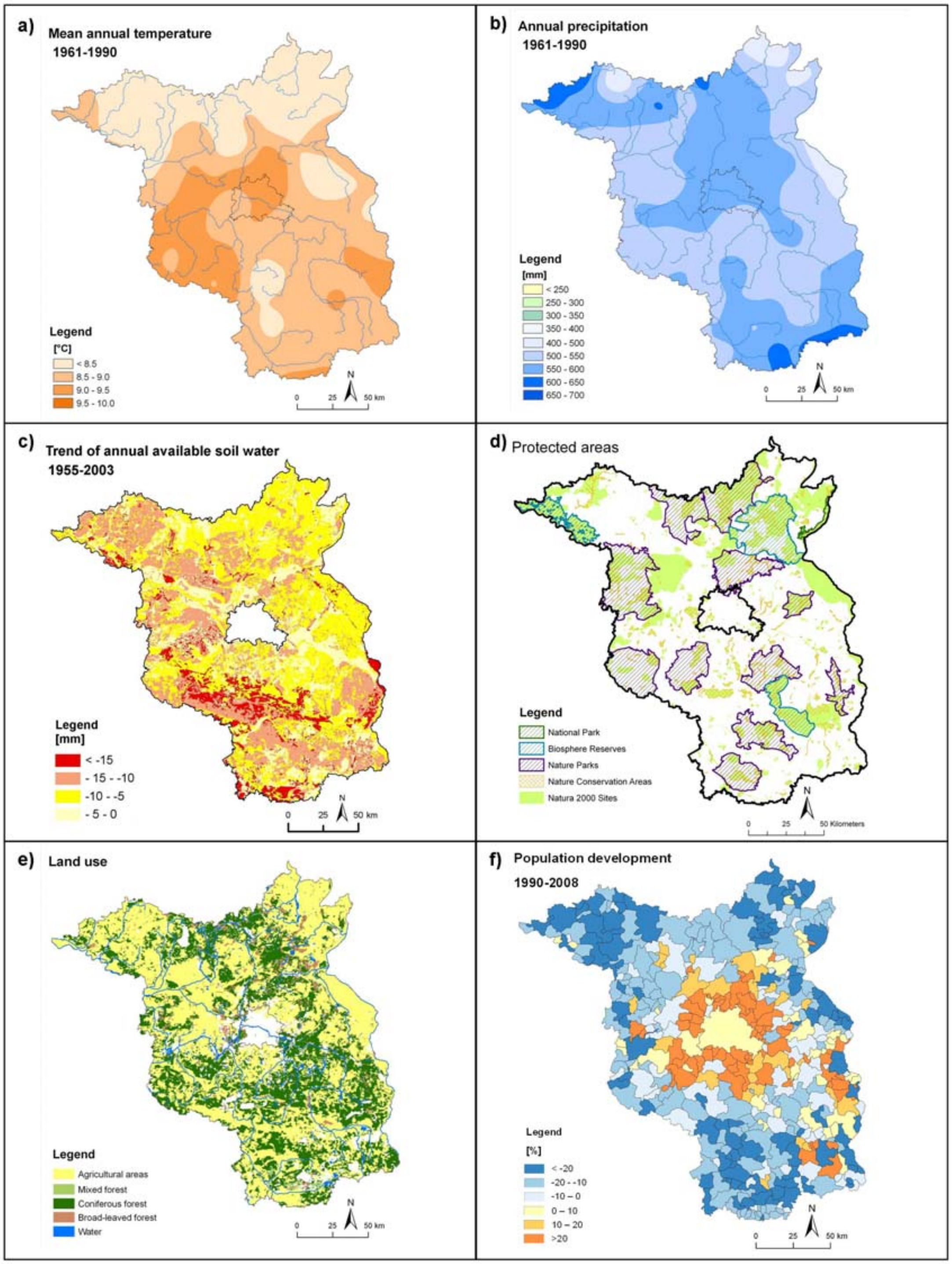

Fig. 2 Current climate, hydrological and demographic situation and land use in Brandenburg: a) mean annual temperature (1961-1990), b) annual precipitation (1961-1990) (temperature and precipitation data of the German Weather Council processed at PIK in 2010), c) simulated trend of annual available soil water from 1955 to 2003 (modified from Holsten et al. 2009, d) protected areas (data from the Federal Agency for Nature Conservation), e) land use (data from the CORINE Land Cover 2000 data set of the Federal Environment Agency) and f) demographic trends (modified from the cartographical service 'Strukturatlas Brandenburg' of the State Office for Building and Transport).

6. Approaches and strategies to climate change adaptation

The federal state government of Brandenburg, advised by its 'Council on Sustainable Development and Resource Protection', has developed a position paper for a sustainable development strategy (MUGV 2011) and a catalogue of possible adaptation measures (MLUV 2008). The former highlights the need for adaptation in all sectors and refers to the latter, which is, however, neither prescriptive, nor bound to specific temporal or spatial scales. In the following, we present existing and presently discussed sectoral approaches from scientific articles, reports, publicly available agency documents and other sources.

a. Forestry

Forest ecosystems in central Europe face considerable impacts of climate change (Lindner et al. 2010) and forest management has to find ways to adapt without the spatial and temporal extent of these impacts as well as their interactions being fully understood. While regional climate change may induce an increase in forest growth (Lasch et al. 2002) which is a potential advantage of global change, it remains unclear under which conditions productivity increases will occur, which species will benefit the most, how long the productivity increase will last and what the interactions with disturbances are. Since forests and forestry are an important part of Brandenburg's landscape and rural economy (see section 5) the adaptation of forests and forest management are of high concern to regional decision makers and stakeholders. The 'Eberswalde Declaration', the result of a conference bringing together actors from more than 70 different institutions, administrative bodies, and associations in 2008, highlighted 11 statements that stress the importance of active adaptation (Spathelf et al. 2008). Generally, forest management practices are already available that enhance the adaptive capacity of forests (see also Table 1; Spittlehouse and Stewart (2003); Seppälä (2009)). Site-specific tree species selection has been a fundamental principle of forest management in Germany for decades. Additionally, in the last 20 years close-to-nature silviculture has become the dominating approach for shaping the forests towards a better presence of a region's natural species, more natural regeneration as well as stable and diverse mixed stands (von Lüpke 2004; Röhrig et al. 2006). Thus, the large-scale, monospecific, and mostly coniferous forests in Germany were and shall be gradually converted into mixed broadleaved/coniferous stands. The greater resilience and stability of site-adapted, species-rich and structured forests has been proven several times (see the review by Knoke et al. 2008). Furthermore, inter-specific competition in mixed forests may to a certain degree shelter some species (e.g. European beech (*Fagus sylvatica*)) from the effects of drier and warmer conditions of a changing climate (Reyer et al. 2010). Whereas globally, forest agencies seem to be in an early stage of adapting forest management to climate change (Eastaugh et al. 2009), Brandenburg's forest administration already pursues programs with important adaptation aspects. Since the 1990s, the forest administration of the Brandenburg region is promoting the conversion of the still dominating pure Scots pine (*Pinus sylvestris*; 73% of forest area) forests for ecological reasons such as lower susceptibility to storm, fire, and insect damage (MLUV 2007). The forestry section of the 'Catalogue of countermeasures for climate change mitigation and adaptation of the federal state government' (MLUV 2008) focuses on forest conversion towards diverse forests, with small-scale species mixes adapted to micro-site conditions and greater importance given to secondary species. In practice this leads to an insertion of broadleaved trees (primarily oaks (*Quercus robur*, *Quercus petraea*) and European beech) into the mono-specific pine plantations, mostly by underplanting in groups. The current area of convertible pure pine stands in Brandenburg amounts to 150 000 ha (roughly 15% of the forest area). Various research projects such as 'Oakchain' (Elmer et al. 2009) or 'Zukunftsorientierte Waldwirtschaft' (MLUV 2005) have not only addressed the ecological benefits of forest conversion but also its effects on the entire wood production chain of custody and even explored alternative possibilities of wood utilization such as 'thermowood' i.e. thermally treated wood to substitute tropical timber.

Besides converting mono-specific coniferous plantations into mixed broad-leaved forests, there is a portfolio of potential measures for adapting silviculture and forest management to global change at the stand level, such as adjusting rotation length, species and provenance choice, thinning strategy and type of regeneration (Bolte et al. 2010). These measures are often discussed in light of their economic, social and ecological impacts. Among practitioners and especially private forest owners there is substantial debate on the future role of non-native species, such as Douglas-fir (*Pseudotsuga menziesii*). In general, several exotic tree species (besides Douglas fir e.g. red oak (*Quercus rubra*), black locust (*Robinia pseudoacacia*), grand fir (*Abies grandis*)) performed well in terms of growth in Brandenburg in the last decades (Bolte et al. 2010) and are from an economic point of view interesting alternatives to current species. The opinions on Douglas-fir amongst forest stakeholders range from euphoric support of timber producers to requests from forest conservationists to ban and completely eradicate this non-native species. Emotional and ideological arguments dominate this debate and alternative approaches such as a careful replacement of the 'non-native' versus 'native' species concept by a 'damage criterion' approach as presented by Warren (2007) are not pursued. Douglas-fir outcompetes native species in terms of growth and its climatic amplitude, especially its lower susceptibility against summer drought, means that it is likely able to cope with a certain degree of climate change (MIL 2009). However, considerable uncertainties regarding its water requirements and natural enemies remain. Especially the main insects damaging Douglas-fir do not occur in Europe yet but are likely to prosper under future climates (Verkaik et al. 2009). In Brandenburg, currently about 1% of the forest area is covered with Douglas-fir-mixed forests or mono-specific stands of a mean size of 1 ha, but the perspective of the state forest administration is to increase this proportion to 5% (MIL 2009). In the case of Douglas-fir, organized and structured communication and participation based on a sound theoretical framework of stakeholder involvement would support judging this adaptation measure.

In general, a forest which offers a variety of different management options for the future in terms of tree species, structure, intervention measures and which is integrated in a landscape management framework will more likely be a resilient/stable and less vulnerable forest (Bodin and Wiman 2007; Millar et al. 2007). Furthermore, such forests provide multiple goods and services as increasingly valued by society (Bengston 1994).

b. Agriculture

Agriculture plays a pivotal role in human societies since it provides food and livelihoods. Therefore its adaptation to climate change is crucial. Many adaptation measures apply to all forms of agriculture since the basic underlying problems are similar and generic to land as a production system. However, since the process of adaptation in organic agriculture tends to be much more complex and difficult than in conventional agriculture (Rahmann 2008) and since Brandenburg shows the highest proportion of organic farming in Germany (10%), we focus our analysis on this category (if not indicated otherwise) to gain insight into the full scope of adaptation challenges and opportunities. Nonetheless, the main findings outlined below (reduced tillage) pertain also to conventional agriculture in slightly modified form.

As shown in section 5, farmers in Brandenburg cultivate fields that primarily tend to be characterized by sandy soils with low available water capacity and severe sub-soil compaction. This highlights the strong sensitivity of organic as well as more traditional farming particularly to the projected climate change impacts in Brandenburg, warming and decreasing summer precipitation (see section 5). One of the main reasons for the vulnerability of organic farming systems besides reduced water availability during summer droughts is the nitrogen limitation of these systems. Nitrogen supply of organic farming systems is particularly susceptible under expected climatic changes: On the one hand, dry early-summer periods reduce the nitrogen mineralization (Standorf and Epstein 1974; Leiros et al. 1997), which may result in significant nitrogen deficiencies and yield losses especially in winter wheat. On the other hand, increasingly mild and humid winters increase the risk of nitrate losses through enhanced mineralization and leaching (Fig. 3; Standorf and Epstein 1974; Lükewille and Wright 1997; Rustad et al. 2001; Thomsen et al. 2010). The limitation of the nitrogen supply is further aggravated as the forage supply is extensively based on in-farm forage production with legume-grass swards according to the organic farming guidelines (EC 2007). Thus, forage losses caused by drought periods or intense rain events can only be compensated by expensive bought-in forage. Moreover, forage deficiencies imply a significant reduction of nitrogen input. Short-term reactive adaptation measures for the optimization of the water and nitrogen supply such as the application date and amount of mineral nitrogen fertilizer or feed purchase are strongly restricted in organic farming. Above all, the use of evaporation-reducing mulch systems is largely excluded due to the prohibition of total herbicides. Therefore, the challenging task is to improve the water and nitrogen supply for Brandenburg’s organic farms to minimize climate change related risks and impacts.

Generally (and not only restricted to organic farming), existing farming system types differ significantly in scale, intensity, and efficiency, therefore requiring a broad portfolio of adaptation measures (see also Table 1). Besides (i) the selection of cultivars tolerant of water stress, (ii) adapted pasture management of hydromorphic grasslands and (iii) agroforestry systems (for more adaptation options see Bindi and Olesen 2011), the regionally most important and promising adaptation strategies of agricultural management aim at reducing tillage to reduce soil erosion, improving water infiltration, reducing evaporation and improving soil structure. Semi-quantitative approaches to assess climate impacts and support strategic decisions are also important adaptation measures (e.g. Schaap et al. 2011).

Due to the restrictions in organic farming systems mentioned, adaptation measures for organic cropping systems must primarily rely on strategic long-term planning. Therefore reduced soil tillage combined with modified tillage and sowing dates and catch crop use are being developed and tested as adaptation measures. An altered tillage device (e.g. a ring cutter) aims at preserving the soil structure, allows a shallow overall root-cutting thus enhancing infiltration, increasing soil water availability, and reducing soil erosion through surface run-off. Simultaneously, shallowly incorporated crop residues reduce evaporation and increase earthworm activity. In comparison, conventional plow tillage increases the soil's susceptibility to erosion, compaction and water losses (Eitzinger et al. 2009). Despite these inconveniences, organic farmers use plowing as a standard measure for controlling perennial weeds and to kill legume grass swards effectively. Above that, the intensive loosening of the top soil increases the microbial nitrogen mineralization within the main growing period, resulting in higher yields (Kahnt 2008). Summer crops can be well established in time also under wet soil conditions, where plowing would probably cause further soil damage. Furthermore, the establishment of legume grass and cover crops on dry soils in summer could be improved by minimizing evapotranspirational water losses. These advantages of a new device such as a ring cutter exemplify that there are new management options for climate-adapted crop production. These climate-adapted production activities can be integrated into PC-based cropping system planner (e.g. ROTOR of Bachinger and Zander 2007) and can, in combination with site-specific risk assessment for forage and nitrogen supply, support cropping planning decisions. To introduce new devices such as a ring cutter, communicating its advantages and discussing its application with stakeholders is crucial. This will increase the adaptive capacity of Brandenburg's organic farming sector.

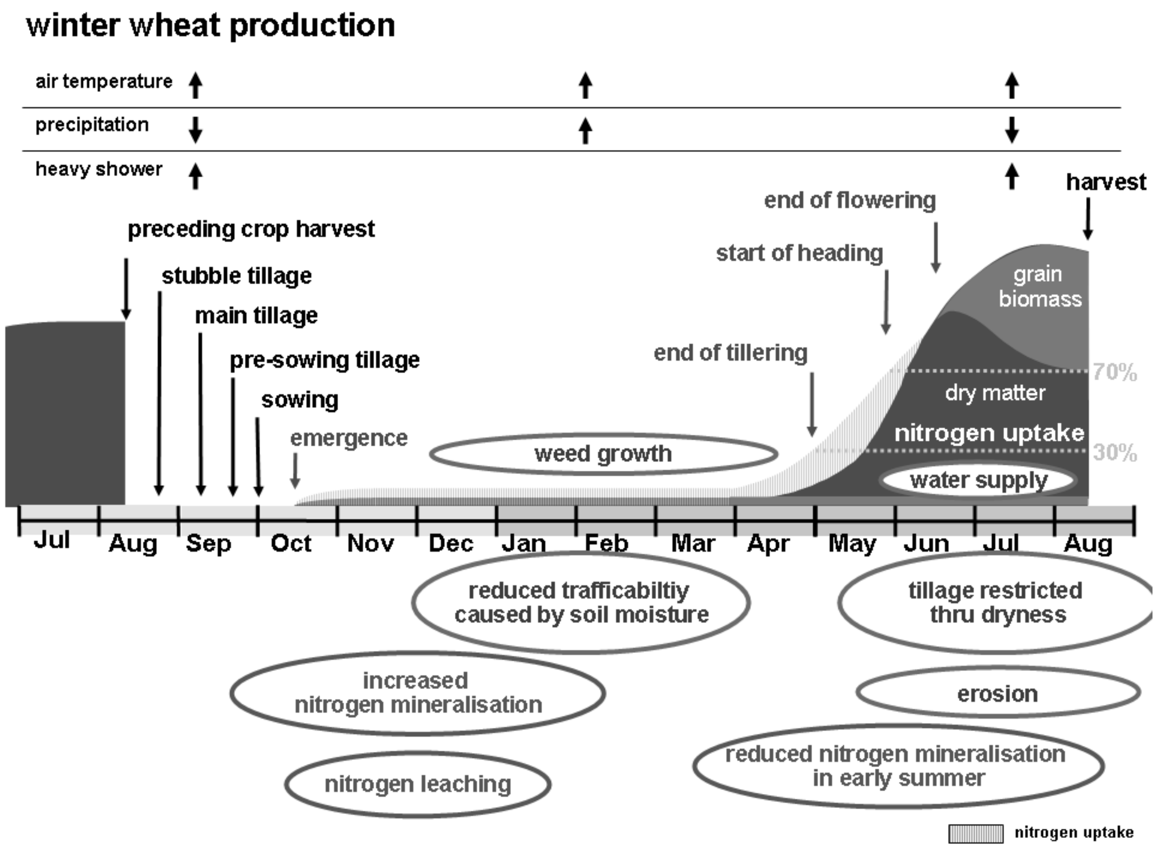

Fig. 3 Climate change impacts on cropping planning of winter wheat production. The bold arrows at the top of the figure indicate seasonal climate changes, whereas regular arrows in black indicate management interventions and regular arrows in grey indicate phenological events.

c. Water management

In an already dry region such as Brandenburg, which faces even drier future summers, managing water is crucial. In Brandenburg, climate change impacts on water resources and the future development for hydrological extremes (floods and droughts) are among the main concerns. Many recent investigations (e.g. Huang et al. 2010; Hattermann et al. submitted) highlighted the challenges that result from shifts in precipitation patterns and snow regime, changes in seasonal water availability and water quality, rise of sea level, and increase in the frequency and/or intensity of river floods and droughts, all coupled with the rise in mean surface temperature. The State of Brandenburg has been struck by several severe river floods in the last 15 years, and the scenario projections show that the intensity of floods will most likely increase under climate change (Hattermann et al. 2011). Furthermore, as discussed in the previous sections, the water sector strongly interacts with forestry and agriculture and water management is therefore a cross-sectoral issue.

Similarly to the other sectors, general adaptation measures are available. Table 1 lists possible technical and management strategies to adapt to regional climate change in the water sector (for a larger set of possible measures cf. Kabat et al. 2002). Most of the measures proposed also help to adapt to the already observed climate variability such as an already carried out or planned raising and relocation of dikes and can thus be classified as 'no(or low)-regret measures'. Another measure discussed in the framework of climate change adaptation, especially to counteract droughts and desiccation of the upper areas of the catchment, is water retention in the landscape to minimize run-off to the sea and to counter decreasing ground-water tables. Therefore water retention and rewetting measures such as those carried out primarily for nature conservation (e.g. in the nature reserve Naturpark Uckermärkische Seen, (Mauersberger 2010)) may entail important co-benefits for adaptation and also mitigation (e.g. by fostering peat formation). The appropriateness of these selected measures and the feasibility of their implementation taking the local characteristics of the natural and social environment in Brandenburg into account have to be discussed in a regional context.

Combinations of technical and management measures represent an appropriate strategy to adapt to climate change because they can be implemented within a single sector and at the local or regional scale. Although they are often meant to decrease the vulnerability to climate change of a single sector or region, they most often affect also the vulnerability of other sectors or regions in a positive or negative way. This can lead to conflicts among different users (cf. section 7a). Therefore, an integrated approach to water resources management (IWRM), especially if it involves relevant stakeholders in the decision-making process, is very important to provide a sustainable and widely accepted management solution (but see also Huntjens et al. (2010) for limitations). Such IWRM at the catchment scale involving the relevant upstream and downstream stakeholders and experts is the backbone of both the EU Water Framework Directive (EC 2000) and the EU Flood Directive (EC 2007b). It is therefore very advisable to link the process of designing management strategies to adapt to climate change with the implementation of these directives (Hattermann et al. 2008).

d. Nature conservation

Due to its natural setting, political circumstances and economically unfavorable conditions throughout centuries, Brandenburg, in western Central European terms, has enjoyed a relatively low level of anthropogenic pressure (e.g., population density, land take rate, pesticide use etc.) on its biodiversity (BfN 2008). Ecosystems in Brandenburg are thus in a better conservation state (e.g., river water quality; LAWA 2000) than the German average. Nevertheless, Brandenburg's biodiversity is facing substantial pressures from various stressors such as habitat degradation, fragmentation, and loss. Climate change is emerging as an additional anthropogenic threat and as it is expected to gain velocity, it is prudent to assume that it will interact with the 'conventional' stressors mentioned. The only imprecisely predictable pathway of climate change as well as of societal reactions to it, such as the potential spread of bioenergy crops, and other aspects of global change will together increase planning uncertainty.

Society in Brandenburg through its governments has chosen to address these pressures through the creation of a protected area system of exceptional coverage (e.g., 26.5 % of the territory under more or less strict protection as Natura 2000 sites, the top score of all German states; BfN 2008). The general nature conservation approach is widely static (attempting to preserve remnants of historical cultural landscapes) and segregative, rendering the matrix exposed to increasingly unsustainable use and development. Nature parks and biosphere reserves actually are designed to integrate land use and conservation. However, this approach has lately been weakened by segregatively prioritizing Natura 2000 sites enclosed in them (Ibisch and Kreft 2010a). Management of Natura 2000 sites in Brandenburg is complicated by attribution of all those sites enclosed in larger protected areas to the Environmental Agency, and those sites outside other protected areas to the Nature Conservation Fund. The landscape framework plans ('Landschaftsrahmenpläne') of the municipalities represent another scale and approach to (potential) conservation management.

The landscape planning for the whole landscape was thought to represent a strong instrument of integrative conservation even outside protected areas, but in practice commonly fails to guide socio-economic development driven by productive needs and investment opportunities.

Currently, conservation management planning in Brandenburg generally revolves around very detailed prescriptions for treatments (mowing, grazing, logging etc.) of often small to very small areas that represent narrowly circumscribed remnants of the historical landscape. The elaboration of management plans by contracted specialized consultants is laborious and takes some one to three years, depending on the complexity of the site. Once it is completed, a management plan is meant to serve between six and ten years (varying between protected area categories).

Adaptation to climate change (see also Table 1; Hannah et al. (2002); Lawler (2009)) has not yet found its way into conservation management planning in Brandenburg. At the present, however, conservation managers might be in the process of intuitively becoming more sensible towards accelerating environmental changes – the existent long planning cycles, which do not allow for intermittent adaptations of management, are increasingly criticized as too inert and thus impractical (H. Mauersberger, M. Petschick, L. Thielemann, pers. comm.).

Increased planning uncertainty calls for a proactive-adaptive approach to nature conservation that ultimately serves to enhance the resilience of biodiversity and to reduce its vulnerability (Ibisch and Kreft 2009; Ibisch et al. 2010). Bringing together the 'dispersed' conservation planning and management regimes under one roof would obviously facilitate a spatially as well as institutionally more coherent management strategy. Fundamental contributions to adequately addressing this challenge lie in providing staff and funding that enable conservation administrations to adequately address complex protected area management issues, including climate change, and in properly designing management plans based on the identification of key vulnerabilities of a specific conservation site. Once the vulnerabilities are assessed, it will be possible to deduce adaptation measurements that allow for a proactive conservation management.

A key challenge to the success of protected areas is to reduce the vulnerability of the management. To this end, assessments should be directed to its relevant dimensions: the specific parts of biodiversity defined as conservation targets and associated conservation goals, the spatial conservation design as well as institutional infrastructures (Fig. 4; Ibisch and Kreft 2009; Ibisch and Kreft 2010b). Management options may then build upon the aspects identified as vulnerable in all these dimensions and aim at reducing their vulnerability.

Such vulnerability assessments should form part of systematic, adaptive management planning. The 'Open Standards for the Practice of Conservation' (CMP 2010) are built around an explicitly adaptive management cycle. Management designed under the 'Open Standards' is much leaner than the traditional multi-volume plans and thus both easier and more transparent in its design and implementation. The tool is also inherently participatory, as they require the formation of a project team that comprises all stakeholders relevant for accomplishing of the goals set for the protected areas. As many threats to biodiversity often do not arise locally, but are of regional or even global character, and as the scope of solutions should be guided by natural boundaries (Fee et al. 2009), it appears prudent to invite stakeholders 'systemically', i.e., to include representatives of the forces that influence energy and material flows within the natural boundaries the protected area is situated in.

Looking beyond these practical considerations, modern conservation approaches such as the ecosystem theory (Jørgensen 2006) do not consider nature conservation as 'land use' that occurs in a distinct, segregated sector. In this sense, conservation does not compete with other sectors, but it is rather a higher order interest in protecting biodiversity across scales and maintaining ecosystem functions and services. Hence, suggestions such as the (radical) 'Ecosystem Approach' (CBD 2010; Ibisch et al. 2010) are inherently integrative and offer an important framework for adaptation although they are thus far still in an early stage of implementation in Brandenburg (Fee et al. 2009). Current 'mainstream' lines of thought of adaptation of nature conservation to climate change which focus on ecological networks that allow the movement of animals and plants and thus range shifts of population and species can be easily embedded in such an adaptation strategy.

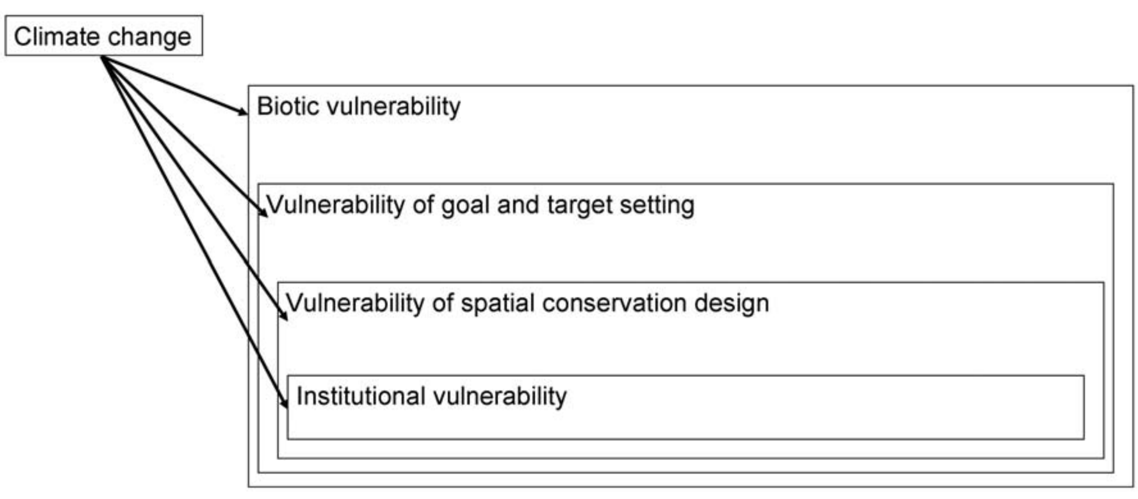

Fig. 4 The four dimensions of vulnerability of protected areas and other 'conservation systems' as affected by climate change (adapted from Ibisch and Kreft 2009).

Table 1 Potential adaptation measures and strategies in Brandenburg resulting from the references cited in the sections 6a-d and from the authors' personal experience

Forestry

- silvicultural management:

-conversion of conifer plantations in close-to-nature forests
-species and provenance selection
-provenance trials
-management of stand densities and regeneration

- hydrological management (e.g., reduction of drainage)
- development and marketing of alternative wood products (e.g. 'Thermowood')

Agriculture/organic farming

- reduced tillage (e.g. ring cutter)
- strategic long-term planning (e.g. ROTOR)
- modified sowing dates
- catch crops

Water

- flood protection:

-improvement of technical flood protection (e.g. dikes, reservoirs, drainage systems)
-restoration of natural retention areas and increase of infiltration capacity
-restriction of settlement/building development in risk areas
-adjusting standards for building development (e.g. permeable surfaces, greening roofs)

- drought/low flow protection:

-improvement of technical measures to increase water availability
-increasing of water retention
-increasing efficiency of water use (e.g. leakage reduction, use of grey water)
-economic incentives (e.g. water pricing)
-restriction of water uses in times of shortage
-landscape planning measures to improve water balance (e.g. change of land use, forest conversion)

Nature conservation

- adoption and implementation of principles of CBD's Ecosystem Approach:

-adaptive management
-management in adequate dimensions of space and time
-acceptance of change (dynamic instead of static goal-setting)

- identification of and management for functional conservation targets and goals (e.g. water-retention, re-wetting)
- coherence/ better coordination and cooperation of protection initiatives
- reduction of institutional fragmentation
- enhancement of ecosystem connectivity

General adaptation measures

- awareness raising, information campaigns
- forming of financial resources
- improving risk assessments and general information flow
- improving insurance schemes against climate change damage

7. Systemic perspective on conflicts and synergies between adaptation measures and common practices or regulations

The adaptation measures mentioned above (see also Table 1) are all measures which are actually carried out, planned or under research to become operational. While this does not necessarily mean that they will be adopted, but they are all supported by some decision makers or stakeholder groups. At the level of Brandenburg (and sometimes even beyond) they may however conflict or offer synergies either with current practices or regulations or with other adaptation measures.

a. Conflicts

Since strong concerns over the future water availability are common not only in the water sector but also in forestry and agriculture, water management bears a strong conflict potential. Retaining water in the landscape (e.g. in wetlands or bogs for nature conservation) leads to an increase of evapotranspiration, as plants can satisfy their water demand from groundwater in periods with low water availability, especially in late summer. This substantially influences the discharge of rivers with implications for the transport (shipping) and other sectors (e.g. the energy sector) operating downstream. Thus, in reference to the conceptual model in Fig. 1, rewetting measures have positive effects on the ecological aspects of nature conservation but may negatively affect economic aspects of other sectors. Moreover, building reservoirs for drought and flood mitigation as well as rising and relocating dikes can have severe impacts on river ecology. Hence, inducing positive effects on social and economic aspects of the water sector threatens ecological aspects of the water sector and nature conservation. Furthermore, intensifying wood production (e.g. by inserting Douglas-fir in forests) under climate change may counter water retention measures for an improvement of the regional water balance. Additionally, the use of non-native species such as Douglas-fir strongly conflicts with current concepts of nature conservation. Moreover, current, static nature conservation concepts and corresponding management planning generally collide with dynamic, proactive, and adaptive concepts (c.f. section 6d). Due to its overarching character, nature conservation is not only affected by climate change impacts on protected areas and individual species (see e.g. Loarie et al. 2009) but has to cope with natural resource use systems (such as forestry, agriculture…). Fields and forests connect protected areas but by reacting to climate change their managers raise directly or indirectly new threats to nature conservation goals (e.g. insertion of non-native, climate-resilient species or increased biomass extraction on agricultural and forest land). Moreover, current practices and regulations and conflicting interests and values restrict several adaptation options much more than technological or ecological constraints: The certification rules in organic farming restricts short-term reactive measures such as buying extra forage and using mineral fertilizer or forest conversion threatens the steady supply of pine wood to the forest industry. This highlights the importance of "social limits" to adaptation (Adger et al. 2009). Other conflicts are listed in Table 2.

b. Synergies

Similarly to the situation for conflicts, the most obvious synergies also relate to water management. Besides the positive effects of a rewetting of wetlands and bogs for nature conservation (e.g. restoration of habitats), these measures improve the regional water balance and help to buffer heavy rain events and floods (i.e. positive side-effects for water management, although rewetting is not primarily an adaptation measure). When floods occur, they ease the pressure on dikes. Furthermore, the building of reservoirs and improved reservoir management influences the hydrograph of the entire river and can improve drought mitigation (water release to augment low flows, water storage for irrigation), and also flood retention. These measures in the water sector also protect infrastructure and people.

An important economic co-benefit of forest conversion is that diverse forests provide a broader range of forest products and services. Most importantly, however, the adaptation measures of the individual sectors as well as the new view of nature conservation presented here all refer to an "integrated management" and strategic long-term planning which includes communication with other sectors and stakeholder participation as an important adaptation measure. The climate change impacts combined with the socioeconomic challenges pose common threats to the individual sectors. This creates a truly cross-sectoral problem which establishes a common ground for discussion and action: Actors which are usually more or less opposed have now a common problem at the regional level which may constitute an important window of opportunity to improve communication and dialogues. Other possible synergies are listed in Table 3.

Table 2 Possible conflicts of adaptation measures with current regulations, practices, and other adaptation measures (non-exhaustive list) resulting from the references cited in the sections 6a-d and from the authors' personal experience

	Forestry	Agriculture	Water	Nature conservation
Forestry			Intensification of wood production (e.g. tree species choice) results in higher water use and reduced ground water levels	Non-native species (e.g. Douglas-fir)
Agriculture			Water use for irrigation reduces river discharge	
Water		Water retention in landscape and reservoirs reduces water availability for irrigation		Water reservoirs and raise and reallocation of dikes impact riparian ecology
Nature conservation	Larger 'wilderness' areas and reduced management intensity constrain wood production More structural diversity and importance of deadwood constrain forest management	Embedding more structural landscape elements in the agricultural landscape and connecting protected areas constrain production Reduction of landscape drainage/re-wetting leads to production losses	Rewetting of bogs and fens reduces river discharge	

Table 3 Possible synergies of adaptation measures with current regulations, practices, and other adaptation measures (non-exhaustive list) resulting from the references cited in the sections 6a-d and from the authors' personal experience

	Forestry	Agriculture	Water	Nature conservation
Forestry			Forest conversion enhances water balance	Forest conversion increases biodiversity
Agriculture			Drought-adapted crop species enhance water balance	
Water	Water retention in landscape (e.g. rewetting, reduced drainage) mitigate drought and desiccation	Water retention in landscape (e.g. rewetting, reduced drainage) and reservoir management mitigate drought and desiccation		Water retention benefits bogs, fens and wetlands
Nature conservation	Structural diversity leads to higher resilience, improved forest health and a diversification of (financial) risks	Organic farming reduces costs for fertilizer while increasing marketing opportunities	Bog rewetting and restoration improves regional water balance	

8. Adaptation of the "Brandenburg system"

Past and future climatic changes and their impacts in each individual sector in Brandenburg can be interpreted as 'non-routine' climate variability and impacts defined by Dovers (2009) as "significantly exacerbated degree of variability and related impacts […] not outside the historical human experience" to which adaptation is possible. However, Nelson (2010) points out that the ability to adapt emerges from relationships within a system (the relationship in between sectors and also the influence of the socioeconomic situation in our case).Thus, if adaptation strategies in different fields are not compatible and lead to conflicts between sectoral adaptation activities and stakeholder groups this hampers their successful implementation. The interaction of adaptation measures between individual sectors constrain the coping range of Brandenburg as a system beyond of what an analysis of each sectors' individual coping range would suggest (Smit and Wandel 2006). Adapting intensive agricultural production through irrigation conflicts with adaptation to high flow situations through increasing water retention in the landscape. Furthermore, stakeholders with different interests and values may oppose or favor certain adaptation options. Whereas private forest owners may consider Douglas-fir as an appropriate adaptation option and object to structured multi-species stands, the opposite may be true for nature conservationists. Individually, each measure seems to be a valid adaptation option but at higher organizational levels their implementation is contested and therefore restricted.

Furthermore, present and future socioeconomic conditions including cultural values can determine a system's vulnerability to a larger extent than climate change and undermine its resilience (Burton et al. 2002; Redman and Kinzig 2003). If the socioeconomic situation or the infrastructure in an area do not allow for water retention measures in the landscape (e.g. because this is fertile agricultural land or an important traffic intersection), expensive flood protection will have to be built. Similarly, static nature conservation concepts shaped by a long history of nature protection in the absence of needing more dynamic approaches in view of changing conditions determine how protected areas are managed even when conditions are now more in flux. Furthermore, the availability of a skilled work force constrains the successful implementation of adaptation measures if these require better technical knowledge than conventional measures. A climate change-adapted forest management unit with several tree species may require more complicated silvicultural systems and planning than a conventional Scots pine monoculture. However, Wechsung et al. (2008) also found that climate change-induced yield losses on agricultural lands may be compensated by increasing prices.

Most of these issues are strongly dependent on the demographic development in Brandenburg which continues to face substantial challenges (see section 5). Although adaptation measures are available, mainstreaming, information of and communication with relevant stakeholders and the public, planning, financing, demographic development, and employment as well as current practices, laws, values, and administrative practices remain important barriers to their implementation. Such barriers may be more easily resolved if strong and visible impacts with immediate implications for society occur (e.g. in the water sector through floods) since these receive high public attention and make resources available (Adger et al. 2007). However, such events also distract public opinion and funding from effective adaptation (Adger et al. 2007) and thereby increase the risk of ignoring slowly changing variables which take an important part in shaping system dynamics (Carpenter and Turner 2001). A slowly decreasing water availability has strong impact on the productivity of forests and agricultural land but if no 'obvious' drought damage occurs these effects are hard to quantify and it is difficult to receive support for adaptation. Such changes become, however, increasingly important if not only climate change impacts are considered but also the wider framework of global change, competition for resources and limited funding and its cascading impacts on socio-ecological systems. Moreover, we only highlighted here the most prominent socioeconomic challenges that pertain to the whole region. Locally, the situation may be even more complicated which further hampers adaptation and exacerbates global change impacts.

Thus, although our review of current and planned adaptation measures shows that adaptation in each sectors seems feasible (see section 6), this may not be the case at the Brandenburg level. The conflicts outlined in section 7 support this view and emphasize that cross-sectoral approaches are necessary, especially in water management. Our analysis shows that even in a 'developed country' like Brandenburg successful adaptation at the regional level requires more efforts than perceived by individual actors, which challenges common perceptions of developed countries to “adapt when necessary” (Burton et al. 2002). Therefore ‘no/low regret’ activities that foster climate change adaptation but also entail non-climatic benefits and reduce vulnerability (such as rewetting bogs to restore natural habitats), represent a crucial added value for climate change adaptation and may help to overcome implementation barriers (e.g. by providing new funding possibilities) (Smit and Wandel 2006; Klein et al. 2005; Dovers 2009). A recent study on adaptation in the United Kingdom came to the conclusion that non-climatic aspects drive adaptation activities currently carried out and that these often have significant co-benefits (Tompkins et al. 2010).

These points highlight the importance of focusing on the adaptation of Brandenburg as a system of nested subsystems that are strongly interdependent. This also allows benefiting from the synergies we identified that emerge from the interplay of adaptation measures in different sectors. Moreover, a more systemic perspective is a first step to avoid externalities of adaptation measures that increase a system’s vulnerability (Turner et al 2010, Adger et al. 2007). This implies that although local site conditions determine adaptation measures, adaptation has to occur at the landscape level and in an integrated manner (Heinimann 2010). Such an approach to climate change adaptation has strong linkages with sustainable development.

9. Implications for sustainable regional development

a. Linking adaptation and sustainable regional development

The basic linkages between climate change and development are clear: climate change results form socioeconomic development which in turn determines the vulnerability to climate change and the adaptive capacity of societies (Klein et al 2005). Integrating climate change adaptation into broader policy processes such as sustainable development is known as ‘mainstreaming’ and its high importance is one of the main conclusions of the IPCC Fourth Assessment Report’s chapter on adaptation (Adger et al. 2007) as well as of more recent development studies (e.g. Munasinghe 2010). Smit and Wandel (2006) argue that adaptation is more likely to be successful in the long-run if combined with sustainable development. More concretely, one recent line of research on climate change adaptation policies and development argues that for adaptation to be successful it should focus on reducing vulnerability by increasing adaptive capacity rather than adjusting to the impacts of climate change alone (Burton et al. 2002; Schipper 2004; Klein et al. 2005; Schipper 2007). Adaptation strategies detached from development considerations will only partly be able to address the different levels and facets of vulnerability. The large range of impacts of global change that occur in ecological systems but that have an immediate connection to the vulnerability of social systems underline this mismatch. Adaptation as such will not lead to efficient and equitable development and therefore not respond to the aspirations of societies. These can only be fulfilled if adaptation is embedded in a larger sustainable development context, which implies that sustainable development is the priority and then adaptation a logical consequence (Schipper 2007). The importance of a systemic, holarchical view (c.f. section 8) provides evidence that adaptation should be fully integrated into regional sustainable development policies (and not only into sectoral development) to mediate conflicts and synergies between sectors and to reconcile comprehensive strategies with local realities (Fig. 5). The position paper on sustainable development of the federal state government of Brandenburg highlights the importance of further developing adaptation strategies and considering them in the sustainable development strategy which should be published until 2014 (MUGV 2011). A full integration of adaptation and sustainable development as well as links with vulnerability reduction are, however, not envisioned. For Brandenburg, which is part of one of the richest countries in the world but faces substantial socioeconomic problems combined with strong climatic impacts, these are pivotal conclusions. They entail far-reaching transformations of management processes and practices, a rethinking of how to combine and integrate sectoral adaptation measures and development policies, and a reconciliation of conflicting time- and spatial scales of adaptation and development priorities to create a resilient social-ecological system. This would also facilitate the integration of other strongly debated issues such as coupling Brandenburg’s biomass strategy (MUGV 2010) with a larger land use concept as proposed by the ‘Council on Sustainable Development and Resource Protection’ (Council on Sustainable Development and Resource Protection, unpublished).

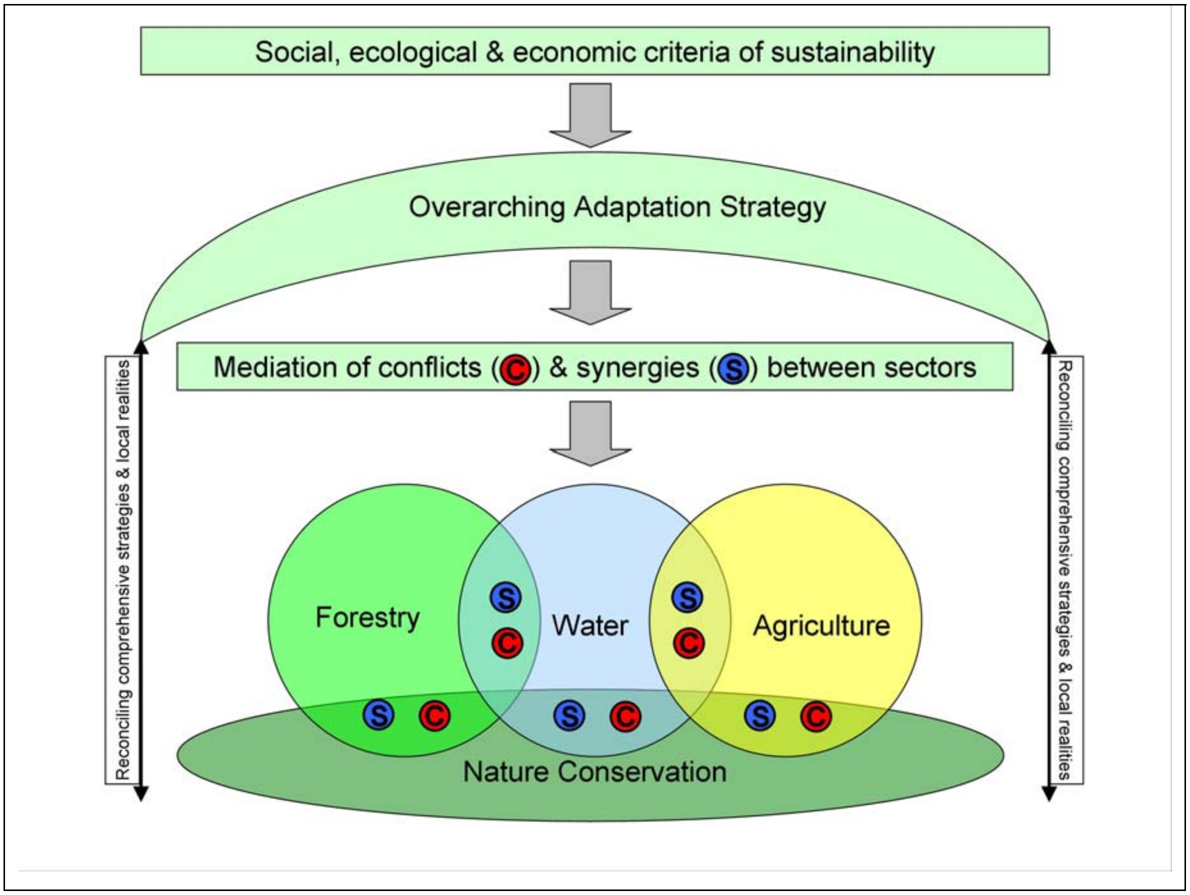

Fig. 5 Conceptualisation of the integration of an overarching adaptation strategy into a broader context of sustainability. The overarching adaptation strategy supports the mediation of conflicts and synergies between sectors and strives to reconcile local realities with comprehensive, higher order strategic issues. The sectors are consistent with those addressed in the text but could be other sectors as well. Note that nature conservation is not a sector per se but rather happens in all of the other three sectors.

b. Adaptation and development for resilient social-ecological systems

Linking adaptation and sustainability as described above points towards building resilience since resilience is the concept for understanding and managing change in socio-ecological systems (Folke 2006). A systemic perspective such as presented here which takes into account multiple drivers of change (e.g. climate change, unemployment), different actors (e.g. forest owners, farmers, nature conservationist, and tourists), and possible feedbacks (e.g. forest conversion provides deciduous wood to forest industry which in turn support further forest conversion) enhances resilience (Nelson 2010). Moreover, the “resilience of a system is not fixed but changes in line with changes in internal and external conditions” as Nelson (2010) puts it, which is crucial for both adaptation and sustainable development in times of changing environmental and socioeconomic conditions and evolving values. Resilient systems may benefit from change and disturbances to transform into new states (Folke et al. 2005). Transformation into new states may be an adaptation option when 'conventional' adaptation options become limited (Nelson 2010). However, when changes are less disruptive, resilience is the basis for making use of opportunities arising from climate change.

In practice, resilience requires novel learning techniques (Tschakert and Dietrich 2010), adaptive governance (Folke et al. 2005) and adaptive management to cope with uncertain climatic and socioeconomic conditions and conflicting user groups across different spatial, temporal and organizational scales. A case study by Tompkins and Adger (2004) concluded that adaptive and community-based management enhances resilience through building of networks and maintaining the resilience of ecological systems. Adaptive management also highlights the importance of participation. Participation of stakeholders, actors but also the civil society in general as well as cooperation with government agencies is crucial for adaptation and sustainable development since many limits to adaptation and sustainable development are social ones, people are more likely to act if they perceive adaptation being within their powers, and successful adaptation depends to a large extent on values, belief in scientific findings, and ethics (Adger 2003; Lorenzoni and Hulme 2009; Adger et al. 2009; Bohunovsky et al. 2010; Otto-Banaszak et al. 2010). The choice of appropriate methods for engaging local people and stakeholders in adaptation dialogues depends on the specific objectives of the exercise. These objectives may include: identifying research questions, collecting data and knowledge, creative search for adaptation and development options, prioritizing adaptation and development options or the use of limited funds, or resolving conflicts. Small and large group methods such as Focus Groups (Welp et al. 2009a) or World Café (Hoffmann et al. 2011) have been tested successfully in pilot projects, which aimed at identifying priorities, responsibilities as well as urgent research questions. In a recent series of stakeholder dialogues, the need for action resulting from climate change was discussed as well as approaches to adaptation strategies developed (Hoffmann et al. 2011). The methods for engaging different sectors and industries represented by associations and companies, ministries and authorities and by civil society and academia can be applied in regional settings in Brandenburg.

Participation is however not only needed in policy-making and management. Science needs to open also for an extended-peer community (Ravetz 2006). Regional climate adaptation efforts, in particular if seen in the context of sustainable development, need the support from science. The problems are typically not well-structured, characterized by great uncertainties and conflicts of interest (Ravetz 2006). The traditional scientific approach is likely to produce only punctual insights and sectoral expertise. Transition science (Brown et al. 2010) puts emphasis on engaging local people and stakeholder groups. So far people who want to participate are hampered by a lack of organization, expertise and a theory of their work. Integrating local knowledge, new perspectives on research questions is likely to work if people feel there is an urgent issue that affects them. How this new community and collective intelligence can take part in scientific inquire has been conceptually and methodologically discussed by Welp et al. (2006; 2009b).

The challenge for adaptation is that in both forestry and agriculture, for example, multiple actors make decisions concerning the use of their land resources, material input for the production, tree species and crops they choose. These actors base their decisions on different knowledge bases: individual knowledge (personal lived experience), local knowledge (shared community event), and specialized knowledge (Brown et al. 2010). A combination of and respect for these competing knowledge bases needs to be the basis for collective action. Promising avenues for linking lay knowledge and scientific knowledge are provided by combining communication tools (dialogue methods) and analytical tools (Bayesian belief networks, system dynamic modeling) (Welp et al. 2006).

Thus, participation can help to avoid conflicts, to benefit from synergies and thus to combine and integrate sectoral adaptation and development approaches. Reconciling different and partly conflicting spatial and temporal scales of adaptation and development priorities deserve special emphasis in this process as well as in policy-making. In such an adaptive management framework even imperfect vulnerability assessments (due to e.g. the predictive uncertainty of climate and climate impact models (Burton et al. 2002)) help to point out where and who the most sensitive and exposed areas and groups are. This information can then steer sustainable regional development including adaptation. In practice this may result in connected and diverse landscapes of forests, extensively used agricultural land, and waterways which are appealing to locals and tourists and provide multifunctional ecosystem services while supporting local livelihoods (which is not to downplay the possibility that even with focused, well-directed efforts, environmental degradation could be an outcome; but this would certainly be lessened as far as possible).

10. Conclusion and outlook

Here we provide a regional application of Burton et al's (2002) adaptation framework highlighting examples of synergies and conflicts between adaptation measures and linkages to development as requested by the IPCC's Fourth Assessment Report (Adger et al. 2007). We present a first attempt to move not only from an impact to a vulnerability assessment (Burton at al. 2002) but also from a sectoral to a systemic perspective of adaptation in the framework of sustainable development to create resilient social-ecological systems. Next steps towards successful adaptation would be a thorough, systematic analysis of barriers to climate change adaptation (especially social and cultural ones) following e.g. Moser and Ekstrom's (2010) framework, a more detailed analysis of adaptation measures to current climatic variability (even though not termed adaptation, Burton et al. 2002)) to learn from existing experience but also the assessment of possible adaptation measures and their repercussions on the sustainable development of the entire 'system Brandenburg' (i.e. also those sectors not or only marginally covered here). Finally, linking the regional analysis at the level of Brandenburg to larger (national and international adaptation and development issues) to avoid and solve conflicts between these different organizational levels is necessary (Smit and Wandel 2006).

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