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Agricultural land use changes – a scenario-based sustainability impact assessment for Brandenburg, Germany

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ABSTRACT

Decisions for agricultural management are taken at farm scale. However, such decisions may well impact upon regional sustainability. Two of the likely agricultural management responses to future challenges are extended use of irrigation and increased production of energy crops. The drivers for these are high commodity prices and subsidy policies for renewable energy. However, the impacts of these responses upon regional sustainability are unknown. Thus, we conducted integrated impact assessments for agricultural intensification scenarios in the federal state of Brandenburg, Germany, for 2025. One Irrigation scenario and one Energy scenario were contrasted with the Business As Usual (BAU) scenario. We applied nine indicators to analyze the economic, social and environmental effects at the regional, in this case district scale, which is the smallest administrative unit in Brandenburg. Assessment results were discussed in a stakeholder workshop involving 16 experts from the state government.

The simulated area shares of silage maize for fodder and energy were 29%, 37% and 49% for the BAU, Irrigation, and Energy scenarios, respectively. The Energy scenario increased bio-electricity production to 41% of the demand of Brandenburg, and it resulted in CO_2 savings of up to 3.5 million tons. However, it resulted in loss of biodiversity, loss of landscape scenery, increased soil erosion risk, and increased area demand for water protection requirements. The Irrigation scenario led to yield increases of 7% (rapeseed), 18% (wheat, sugar beet), and 40% (maize) compared to the BAU scenario. It also reduced the year-to-year yield variability. Water demand for irrigation was found to be in conflict with other water uses for two of the 14 districts. Spatial differentiation of scenario impacts showed that districts with medium to low yield potentials were more affected by negative impacts than districts with high yield potentials.

In this first comprehensive sustainability impact assessment of agricultural intensification scenarios at regional level, we showed that a considerable potential for agricultural intensification exists. The intensification is accompanied by adverse environmental and socio-economic impacts. The novelty lies in the multiscale integration of comprehensive, agricultural management simulations with regional level impact assessment, which was achieved with the adequate use of indicators. It provided relevant evidence for policy decision making. Stakeholders appreciated the integrative approach of the assessment, which substantiated ongoing discussions among the government bodies. The assessment approach and the Brandenburg case study may stay exemplary for other regions in the world where similar economic and policy driving forces are likely to lead to agricultural intensification.

1. Introduction

Globally, agriculture is facing an increasing demand for food, bio-based energy and fiber products. Nonetheless, numerous

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studies predict that agricultural techniques will adapt to the increasing demand (Makowski et al., 2013). However, adaptation poses challenges for the integration of environmental and socio-cultural services into agricultural production.

Farmers' adaptation to the increasing demand may include changes in the choice of crops, crop rotations, utilization of crops, and intensification of production. Trends include technical solutions to remove yield limiting factors, such as water availability for crops, and increasing use of agricultural biomass as a source of renewable energy. The latter is often supported by government legislation. For example, in Germany, the introduction of the Renewable Energy Law EEG in 2000 resulted in threefold increase of the area of maize (*Zea mays*) and of rapeseed (*Brassica napus*) for bioenergy, reaching 17.5% of the German cropland area in 2012 (FNR, 2012a). Also, the use of irrigation to increase and stabilize crop yields is becoming more attractive, especially in areas with limited rainfall and with soils with limited water holding capacity. Additional reasons for these changes are related to an increasing water demand of new, more productive cultivars, and the prospect of more irregular precipitation patterns due to climatic change. For example, at the current market prices for agricultural goods, irrigation in the German federal state of Brandenburg is already on the verge of becoming economically viable (Münch et al., 2014). Also, a connection between the production of bioenergy and irrigation exists: as farmers become fuel suppliers for power plants, it becomes more important to achieve stable yields even in dry years.

Agriculture is multifunctional. This means that in addition to (private) economic production, it contributes to public goods such as the character of rural landscapes and its ecosystem services (Wiggering et al., 2006; Van Zanten et al., 2013). A simple focus of agricultural management aimed solely at maximizing economic returns can lead to depletion of groundwater resources, erosion, loss of water quality, biodiversity loss and a reduction of socio-cultural services. Although these services become evident at landscape level, which has a spatial scale larger than a farm, it is the decision-making at farm level that affects these services. Sustainable development therefore requires consideration of the balance between the economic production functions of agriculture and environmental and social services. Policies are implemented to incentivize farmers to respect this balance by remunerating for the provision of public goods.

It is important, when making policy decisions that support sustainable development, to acknowledge present and future development trends and their potential economic, social and ecological impacts. Here, we use ex-ante impact assessment (Helming et al., 2011). This integrates state-of-the-art knowledge from various disciplines in order to highlight those risks and opportunities which are inherent in expected trends. We use scenarios of agricultural management to draft different development options. These scenarios provide the opportunity to explore possible future developments through a comparative analysis of alternative driving forces and trends. In spanning a range of options they help to explore rather than predict possible developments (Milestad et al., 2014). We use impact indicators to assess economic, social and environmental effects of the agricultural management scenarios.

The objectives of the study described in this paper were as follows: (i) to develop an indicator based impact assessment method that combines expertise on agricultural management, landscape, hydrology, soil erosion, biodiversity, stakeholder interaction, sustainability to create and analyze agricultural intensification scenarios and (ii) to conduct an integrated ex-ante assessment of regional sustainability impacts induced by farm level scenarios of bioenergy production and crop irrigation. Results had to assist policy stakeholders in identifying sustainability issues that require policy steering.

The scenarios were designed to integrate currently trending assumptions of driving forces and describe their effects on crop choice and crop management at the farm level. Decisions at the farm level were translated into crop distribution patterns at the hectare scale for analysis of scenario impacts. Results were aggregated to the district (NUTS3) scale to derive policy relevance of the assessment. Also, this aggregation allowed the representation of the landscape level of scenario impacts. Scenarios were developed for the year 2025: a time frame that is sufficiently long to allow for major changes in agricultural management, while still being short enough to allow for realistic predictions of climate effects and yield trends.

We chose the state of Brandenburg, Germany, as a case study area because several characteristics may make this area an example for the application of integrated assessments of agricultural development scenarios: large, specialized farms; low soil fertility; high technological level; yield limitations by water; subsidies for agricultural energy production. We anticipate that the trend of increased use of cropland for the production of renewable energy will continue and that irrigation will become more important in the future to increase and stabilize yields. The extent and speed of these changes in agricultural management are largely unknown, as are the sustainability implications of these changes. A few studies have dealt with specific aspects of bioenergy production in Germany (e.g., Dressler et al., 2012; Hennig and Gawor, 2012) and with specific agricultural adaptation scenarios at field sites (Nendel et al., 2014). However, to our knowledge, no integrated impact assessment studies exist that analyze the effects of agricultural intensification on environmental, social and economic indicators at regional level. Such a case study will help to generate spatially explicit systems knowledge of human–environment interactions in land change processes (Magliocca et al., 2014).

2. Materials and methods

2.1. Case study Brandenburg

Brandenburg is the fifth largest German state, and it has a land surface area of 29,640 km^2, of which 45% is agricultural land, most of which (75%) is arable land. Brandenburg surrounds the German capital Berlin and comprises 14 districts. The state's mineral soils are developed on glaciofluvial, periglacial and glacial deposits, aeolian deposits and river sand. Almost two-thirds of the state's territory, mainly with sandy and sandy loamy soil, has a water holding capacity lower than 140 mm (Table 1). Peat soils are excluded from crop cultivation by decree.

Agricultural practice is dominated by large farm enterprises with an average size of 238 ha, which is four times the German average. Mechanization is high, and the labor force is only 1.7 persons per 100 ha on average. Large-scale operations, hired labor and a high mechanization rate result in highly competitive

Table 1
Classification of the water holding capacity (mm) of soils in Brandenburg (area: 29,485 km^2).
Source: Schindler et al. (2004).

Cumulative area (%)	Range (mm)	Description[2]
21	≤80	Very low
34	>80–110	Low
62	>110–140	Moderate
77	>140–170	High
82	>170–200	Very high
100	>200	Extreme high