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Sustainability impact assessment of peatland-use scenarios: Confronting land use supply with demand

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ABSTRACT

Sustainable development of land use is determined by changes of the regional supply of Land Use Functions (LUFs) and the demand of future societal land use claims. LUFs are based on the ecosystem services concept, but more adapted to human land use. In this paper, we assessed two peatland-use scenarios towards sustainable development in Northeast Germany in order to understand their impacts on LUFs and land use claims. For this, we extended an analytical framework designed to confront LUFs with land use claims identified in multi-level stakeholder strategies in a participatory manner. The sustainability assessment was performed with peatland-use scenarios *“Services for services”* and *“Market determines usage”* that favoured environmental and economic land use claims, respectively. Findings revealed possible trade-offs between land use claims for biomass production and regional value creation as well as for peatlands` carbon and nutrient sink, and habitat functions. The core achievement is an extended sustainability assessment framework integrating land use demands of multi-level stakeholder strategies into participatory impact assessment, in a way that land use claims serve as benchmarks for LUFs. This facilitates the understanding of sustainable land use in both supply and demand perspective, and the normative evaluation of ecosystem services.

1. Introduction

Land use changes affect sustainable development (SD) through a set of multi-level, trans-sectoral and cross-policy issues (Söderberg and Eckerberg, 2013; Jordan and Lenschow, 2010; Helming et al., 2008). Land use drivers, including European policies such as the Common Agricultural Policy (CAP; van Zanten et al., 2013); national policies such as the German renewable energy law (*Erneuerbaren Energien Gesetz;* EEG), globalization (Burkhard et al., 2016) and urbanization lead to land use changes in rural and semi-rural areas in Europe. The supply of ecosystem services, and public goods and services provided by multifunctional land use (Schößer et al., 2010) is affected by these policies` tendencies to focus on monofunctional, large-scaled managed agricultural landscapes (Burkhard et al., 2016). Some drivers, such as the 2nd pillar CAP measures, can as well support multifunctional land use systems (Butterfield et al., 2016; Wilson, 2007). In addition, at the regional level, land use is affected by diverse societal targets (e.g., water protection or securing employment in rural areas) that lead to land competition for different purposes (Germer et al., 2011; Harvey and Pilgrim, 2011). Thus, land use changes are always connected with trade-offs regarding multiple societal targets and with intended and un-intended impacts (Wiggering et al., 2006). To assess the impacts of land use changes, manage trade-offs, and develop strategies for sustainable land use, the linkage with the normative concept of SD (Kopfmüller et al., 2001) and integrative and spatially explicit approaches are required (Helming et al., 2011a; Pérez-Soba et al., 2008). These approaches need to interlink endogenous (biogeophysical, socio-cultural and socio-economic conditions) with exogenous (normative values and societal land use demands) factors (Helming et al., 2011a). In this article, we demonstrate such an integrative and spatially explicit approach to assess the impacts of land use changes on SD.

We considered SD of land use as the ability to fulfil an integrated set of societal targets for the dimensions environment, economy and society (Pope et al., 2004; Hansen, 1996). It could be an instrument

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for governments, companies and societal actors with diverging stakeholder targets and normative values, particularly with respect to the importance of the SD dimensions (Lange et al., 2015). But, the operationalization of SD of land use is challenged by the lack of decision-relevant and operationally functioning assessment methods (Pintér et al., 2012; Rounsevell et al., 2012; De Groot et al., 2010; Turner and Daily, 2008; Hacking and Guthrie, 2006; Wiggering et al., 2006). The development and application of such assessment methods is challenged by (i) moving policy targets and the introduction of new policy fields and sustainability indicators (Petit and Frederiksen, 2011), (ii) the complex interrelations and trade-offs between SD dimensions (Pintér et al., 2012; World Commission on Environment and Development (WCED), 1987), (iii) the need for integration of quantitative and qualitative information (Hacking and Guthrie, 2008), (iv) the definition of causal linkages between human and natural interactions (Rounsevell et al., 2012), (v) the link between ecosystem service provision and land use related functions and services with stakeholder preferences, i.e., normative values and societal land use demands (Burkhard et al., 2016; Larondelle and Lauf, 2016; Rametsteiner et al., 2011; Müller and Burkhard, 2007), (vi) the consideration of manifold stakeholder preferences at various governance levels (Cook et al., 2016; Hacking and Guthrie, 2006), and (vii) the participation of stakeholders in the assessment steps (Spangenberg et al., 2015; König et al., 2015; Pintér et al., 2012).

Using an integrative and spatially explicit *ex-ante* Sustainability Impact Assessment (SIA; Helming et al., 2008) of the expected effects of land use changes in specific research sites, this current case study investigated impacts of land use changes to peatlands in Northeast Germany on SD and human well-being. In terms of the *ex-ante* SIA of land use scenarios, it is essential to confront the future region-specific supply of Land Use Functions (LUFs) with societal land use demands (Hermanns et al., 2015; Paracchini et al., 2011; Helming et al., 2011a, 2011b; Pérez-Soba et al., 2008). LUFs are based on the concepts of ecosystem services and land use multifunctionality; they can be used as a practical approach to operationalize stakeholders` preferences for land use. Compared to ecosystem services the LUF concept is more adapted to the human use of the land and more strongly takes account of socio-economic aspects. Schößer et al. (2010) provided a comprehensive analysis of the interrelations between the two concepts. LUFs also conceptualise the services of the land for human wellbeing and are sensitive to the way the land is used, but not necessarily to underlying ecosystem functions. Other than ecosystem services they include services derived from land sealing such as for infrastructure and housing as well as second order services from value chain creation of biomass production. Likewise to the ecosystem services concept, implementing the LUF concept into *ex-ante* SIA has the potential to improve the accountability of spatial planning (Geneletti, 2011). To determine the impacts of land use scenarios on LUFs, Helming et al. (2011a) developed an analytical framework for sustainability assessment of policies affecting the regional supply of LUFs. For the implementation of the analytical framework quantitative and qualitative methods are developed (Helming et al., 2011b). The Framework of Participatory Impact Assessment (FoPIA) employs a qualitative and participatory approach to relate *ex-ante* impact assessments with SD. The FoPIA approach was first described by Morris et al. (2011), who link the expected effects of land use scenarios with the normative preferences of stakeholders by evaluating those perceived scenarios' impacts on LUFs.

Participatory methods identify the normative values and demands of stakeholders related to ecosystem functions and services provided by land use (Palacios-Agundez et al., 2014; Reed et al., 2009). Ollson et al. (2009) developed a goal-oriented indicator framework to support integrative policy assessments of agri-environmental systems. Integrative and science-based approaches are also used to operationalize SD into sustainability rules and assess land use scenarios (Kopfmüller et al., 2001; Grunwald and Rösch, 2011). Pope et al. (2004) and Hacking and Guthrie (2006) highlight the need for an objectives-led impact assessment to achieve a particular vision or outcome defined by integrated environmental, social and economic objectives. Such objectives-led SIA approaches to policies and plans have some advantages. First, they avoid inherent limitations (e.g., trade-offs between the SD dimensions or a lack of direction), unlike approaches that are exclusively oriented towards the triple bottom-line (Pope et al., 2004). Second, they simplify communication with stakeholders and decision-makers about how to achieve policy targets and minimize trade-offs in land use (Ollson et al., 2009).

Hermanns et al. (2015) extended the analytical framework of Helming et al. (2011a). It can specify the supply portfolio of LUFs into sustainability-relevant topics and identify demand portfolios of land use claims within multi-level stakeholder strategies as well. In this way, an objectives-led SIA approach for land use scenarios affecting LUFs was designed. However, knowledge gaps related to the *ex-ante* SIA of land use scenarios at the regional level remain. These gaps include: (i) an analytical framework that links a participatory assessment of the impacts of land use scenarios on the supply of LUFs with the societal demand of land use claims is lacking; and (ii) there is no linkage of identified land use claims as benchmarks for the supply of LUFs. Hence, we extended the analytical framework of Hermanns et al. (2015) for participatory application jointly involving researchers and stakeholders in a case study on *ex-ante* SIA of peatland-use scenarios. To confront the changes of a supply portfolio of LUFs with a demand portfolio of societal land use claims, we adapted the FoPIA approach of Morris et al. (2011). We used findings from Hermanns et al. (2015) for this current case study. The objective of this paper is to apply the analytical framework for the *ex-ante* SIA of peatland-use scenarios and to confront the region-specific supply of LUFs with the corresponding demand of land use claims. The subgoals included: (i) to select sustainability-relevant topics and indicators in a joint approach of co-production with researchers and stakeholders; (ii) to select land use claims as normative benchmarks for the supply of LUFs; and (iii) to assess the impacts of peatland-use scenarios in a participatory assessment workshop.

2. Materials and methods

2.1. Case study

Our research was part of an interdisciplinary research project (development of integrated land management for sustainable land and matter utilization in Northeast Germany; ELaN), which examined land management and governance strategies for sustainable land use in Northeast Germany. Strategies included wastewater utilization in the surrounding of Berlin and alternative peatland-use systems in the federal state of Brandenburg. Here, we focused on peatlands-use systems, for which land use scenarios were developed. At present, Northeast Germany's peatlands are often drained and cultivated for agricultural production with either intensive or extensive grassland. As a consequence the region's groundwater level is decreasing. Under conditions of climate change, this decreasing groundwater level implies increasing conflicts among stakeholders' SD targets, mainly because drying wetlands are understood to lead to decreased biodiversity as well as decreased grassland and forest productivity (Schwand and Steinhardt, 2016; Germer et al., 2011). In addition, drained peatland is a source of carbon thereby reinforcing driving forces for climate changes. Likewise, peatland is understood to be an important target area for climate change mitigation action because of its potential for carbon sequestration (Jarveoja et al., 2016). The biogeophysical conditions of these peripheral rural areas can be characterized as providing marginal agricultural revenues but high-quality habitats and important sink functions for water and matter fluxes as well as carbon sequestration in a near-natural state (Schwand and Steinhardt, 2016). As research site, the peatland areas in the *"Randow-Niederung"* in the county of *Uckermark* in the federal state of Brandenburg were explored in this case study. For a detailed map of the explored peatland areas see Fig. 1.

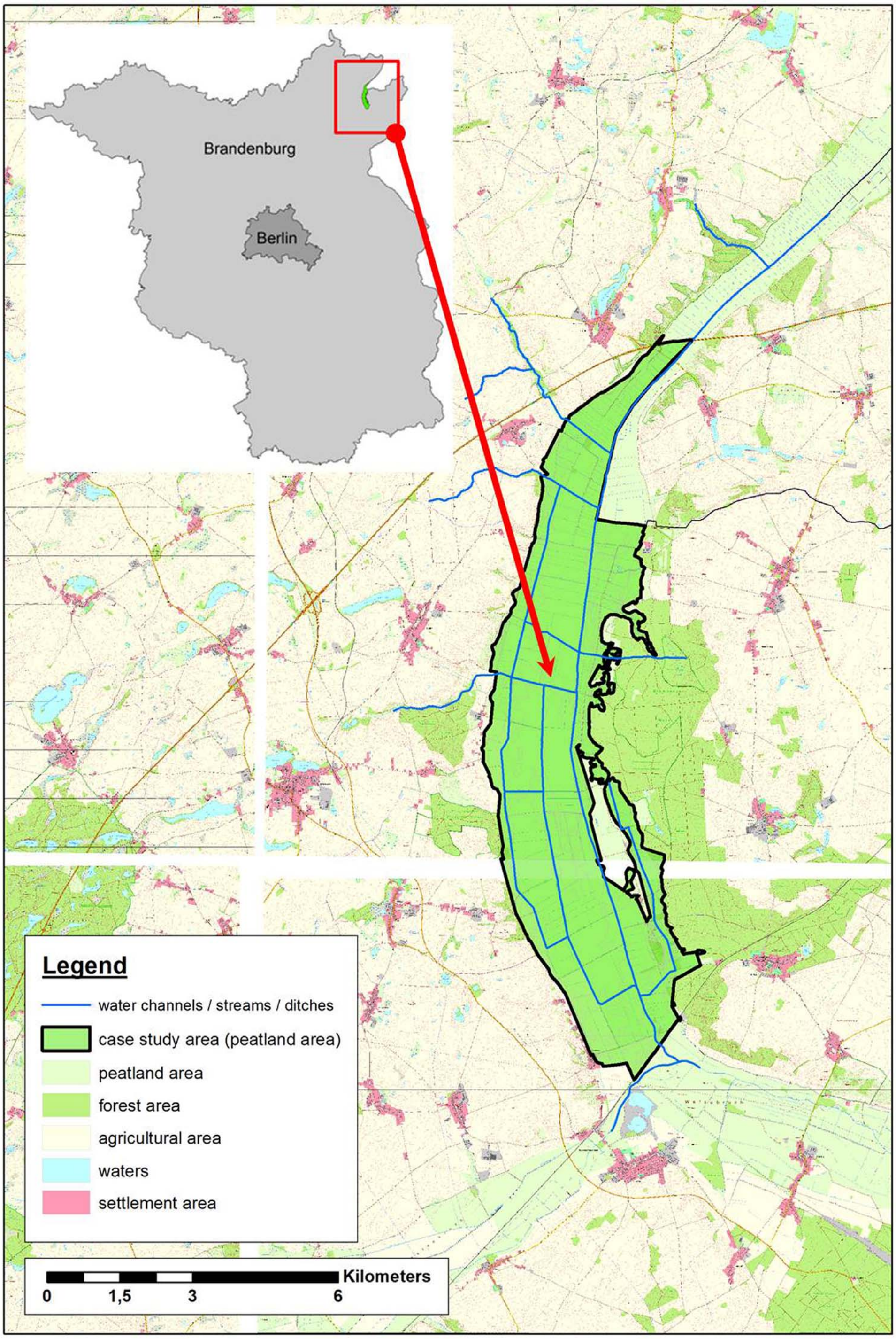

Fig. 1. Map of the peatland areas in the "*Randow-Niederung*" in the federal state of Brandenburg. Reference year: 2008 (Source: Landesvermessung- und Geobasisinformation Brandenburg, Potsdam).

At present, these peatland areas are also intensively used as grasslands and therefore have been drained (on average, 60 cm below the top of the ground surface). The key socio-cultural and socio-economic conditions of the region include a low population density and an unemployment rate that is higher than Brandenburg's average.

2.2. Analytical Framework for Ex-ante Sustainability Impact Assessment

The basis for *ex-ante* SIA of peatland-use scenarios in this study was the analytical approach developed in Hermanns et al. (2015) to confront region-specific supply of LUFs with demand portfolios of land use claims derived from multi-level stakeholder strategies. This framework for the *ex-ante* SIA of land use scenarios is based on the three-dimension model of SD (WCED, 1987). The concept of LUFs serves to evaluate the impacts of assumed scenarios on land use related sustainability issues. LUFs are defined as the goods and services that are provided in a region through land use. They include all of the relevant environmental, economic and social aspects of land use (Pérez-Soba et al., 2008). To guarantee the connectivity of the *ex-ante* SIA with societal discourses about future land use issues (Helming et al., 2011a) in Northeast Germany, sustainability-relevant topics and

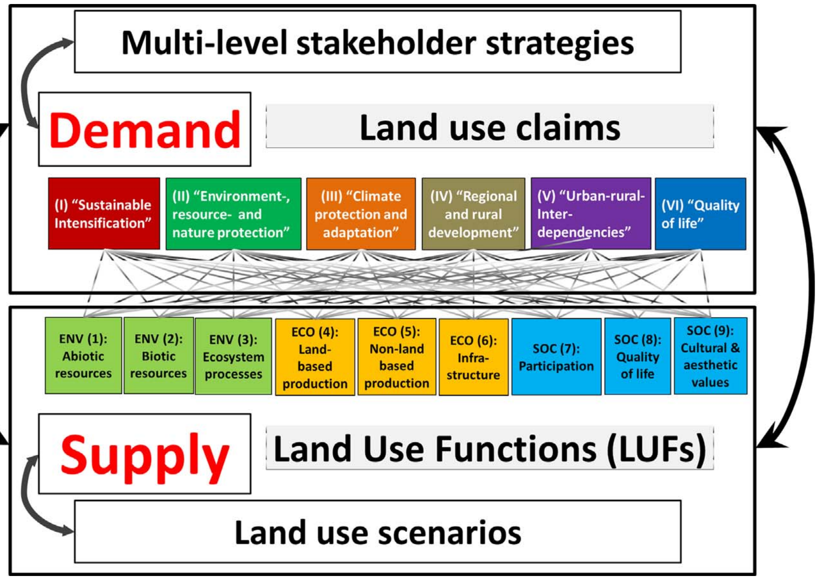

Fig. 2. Analytical approach to a conceptual linkage between region-specific supply (Land Use Functions) and demand (land use claims) portfolios for the *ex-ante* sustainability impact assessment of land use scenarios (extended from Hermanns et al., 2015). While supply is specified into sustainability-relevant topics and indicators and derived from land use scenarios, demand is specified into six main-use claims and related region- and area-specific side-use claims derived from multi-level stakeholder strategies. The achievement of the demand depending on land use scenario again will influence driving forces and the future supply of LUFs (demand-driven land use changes). ENV*= environmental, ECO*= economic, SOC*= social.

SD targets are derived from multi-level stakeholder documents (policies and actors' strategies, and planning concepts). To manage the variety of societal land use demands and the supply of public goods and services, the concept of multifunctional land use (Mander et al., 2007) is applied as a theoretical background. For regional SD of land use, it is important that monofunctionally managed land use systems do not predominate (O'Farrell and Anderson, 2010). Monofunctional land use systems would lead to the maximization of single societal desired SD targets and might endanger other targets related to the three-dimension model of SD.

To hierarchize the impact levels of the stakeholder targets along the levels of the *nomenclature des unités territoriales statistiques* (NUTS), the concept of Environmental Policy Integration is introduced into the cross-strategy analysis of multi-level stakeholder strategies. This step is taken because the concept of multifunctional land use does not adequately take into account the diverse impact levels and possible trade-offs of land use demands from stakeholders in the European multi-level governance systems. Environmental Policy Integration is developed to integrate seemingly incompatible targets for future environmental viability, economic competiveness and social compatibility into multi-level governance (Jordan and Lenschow, 2010). This integration and the special focus on the long-term environmental viability is a precondition for achieving SD of land use (Pintér et al., 2012; WCED, 1987). Regarding the concepts of multifunctional land use and Environmental Policy Integration, changes of region-specific supply and demand portfolios of LUFs and land use claims must be confronted to assess the impacts of land use scenarios on SD. Land use claims, consequently, are defined as the future societal demand for goods and services related to region-specific land use (Hermanns et al., 2015). In a previous study, LUFs are already specified into 44 regional sustainability-relevant topics (Hermanns et al., 2015). In this study, multi-level stakeholder targets are condensed into land use claims in terms of six main-use and 44 related region- and area-specific side-use claims by means of a frame analysis (Söderberg and Eckerberg, 2013) of land use demands in Northeast Germany and on peatlands. A frame analysis has the goal to explore and `make sense of, people's multiple understandings of different situations and phenomena` (Beland Lindahl, 2008, p. 68). The six main-use claims are "land use for" *1) sustainable intensification*, *2) environmental, resource and nature protection*, *3) climate adaptation and protection*, *4) regional and rural development*, *5) rural-urban interdependencies* and *6) quality of life*.

As societal benchmarks for the future supply of LUFs, we relinked these identified land use claims in terms of side-use claims with the sustainability-relevant topics for each LUF. If no area-specific side-use claim was present, we used a region-specific side-use claim to measure humans' wellbeing and SD. This way, we determined the region-specific demand portfolio for LUFs in the context of peatland management in Northeast Germany. Fig. 2 illustrates the linkage of region-specific supply (LUFs specified into sustainability-relevant topics and indicators) with demand portfolios (land use claims specified into main- and side-use claims) for LUFs to operationalize multi-level stakeholder strategies in the context of an objectives-led assessment of the impacts of land use on regional SD.

We applied the *driver-pressure-state-impact-response* concept (DPSIR; Organization for Economic Co-operation and Development (OECD) (1993)) to structure the integrative and objectives-led SIA process. The *ex-ante* SIA process was structured into region-specific assumptions about influencing factors for land use changes (*(D)rivers*), future land use options and intensities (*(P)ressures),* sustainability-relevant topics and indicators to specify the supply portfolio of LUFs (*(S)tates*), and a demand portfolio of land use claims in terms of manifold condensed stakeholder targets for SD (*(I)mpacts*). For our participatory *ex-ante* SIA of peatland-use scenarios we adapted the original FoPIA approach from Morris et al. (2011) both to confront the changes of the region-specific supply with demand portfolios and to calculate qualitative LUFs and land use claim budgets. We took the distance between the projected supply of LUFs and land use claims for LUFs as a benchmark for an objectives-led SIA (Pope et al., 2004) to note sustainability gains and deficits. This way, decision-relevant knowledge for policy-makers and stakeholders and the possible need for actions to achieve SD of land use can be illustrated at an early stage (König et al., 2015; Lange et al., 2015). Table 1 shows the required working steps and analytical approaches to apply the analytical framework from Hermanns et al. (2015) to confront region-specific LUFs with land use claims and to assess the impacts of land use scenarios on SD in participatory assessment workshops. In this way, qualitative LUFs and land use claim budgets can be jointly determined by researchers and stakeholders.

Table 1
Analytical steps and approaches to confront changes of the region-specific supply with demand portfolios of Land Use Functions (LUFs) and land use claims for the *ex-ante* Sustainability Impact Assessment of land use scenarios along the DPSIR concept (extended from Hermanns et al., 2015).

Analytical steps in the DPSIR concept	Analytical approaches (methods / tools)	Purpose and result of each analytical step	General outcome
(D) rivers	**Literature survey, researcher consultation**	Determine assumptions about influencing factors leading to land use changes in a specific area ● **Identify key land use drivers**	**Land use scenarios**
(P) ressures		Determine assumptions about land use ● **Set of land use scenarios**	
(S) tates	**Cross-strategy analysis based on Environmental Policy Integration and multifunctionality, researcher consultation**	Set up database for cross-strategy analysis at different NUTS levels ● **Database of stakeholder strategies** (Hermanns et al., 2015) Define LUFs in connection to SD of land use and public service tasks ● **For the context, specified LUFs** (Hermanns et al., 2015) Identify sustainability-relevant topics and indicators for future land use and link with LUFs ● **Long-list of topics and indicators per LUF** Researcher-based selection of sustainability-relevant topics and indicators ● **Selected topics and indicators per LUF**	**Region-specific supply portfolio of LUFs**
(I) mpacts	**Cross-strategy analysis, frame analysis to condense land use claims expressed in strategy documents, researcher consultation**	Identify SD targets from stakeholder strategies at different NUTS levels and linkage with respective sustainability-relevant topics and LUFs ● **Long-list of SD targets per specified LUFs** Condense SD targets in multi-level stakeholder strategies for land use in Berlin/Brandenburg to land use claims ● **Land use claims in terms of main- and side-use claims** (Hermanns et al., 2015) Re-link identified land use claims with sustainability-relevant topics for the related LUFs ● **Land use claims pursuant to specified LUFs** Researcher-based selection of land use claims ● **Selected land use claims per LUF**	**Region-specific demand portfolio of land use claims**
	Participatory assessment workshop with researchers and stakeholders adapted from the FoPIA approach (Morris et al., 2011)	Weight perceived importance of LUFs for regional SD ● **Weighted scores per LUF** Score land use scenario impacts to confront region-specific supply (LUFs) with demand portfolios (land use claims) ● **Assess qualitative LUFs and land use claim budgets and identify sustainability gains and deficits** Weighted scoring of land use scenario impacts for SD ● **Weighted scenario impacts and trade-off analysis**	**Confronting changes of supply with demand based on land use scenarios**
(R) esponses		Derive implications and recommendations for land use and governance strategies ● **Options to achieve sustainability gains and minimize deficits**	**Options for action**

LUFs=Land Use Functions. NUTS=*nomenclature des unités territoriales statistiques.* FoPIA=Framework of Participatory Impact Assessment. SD=Sustainable Development

2.2.1. Peatland-use scenarios in Northeast Germany

Future land use development is connected with uncertainties (Kröger and Schäfer, 2016; Schwand and Steinhardt, 2016; Kok et al., 2007). Therefore, researchers were asked to make assumptions about possible land use scenarios and to enable an *ex-ante* SIA. The two polarizing peatland-use scenario narratives *PU1, "services for services",* and *PU2, "market determines usage"* were used. They were developed by scientists and elaborated in joint researcher and stakeholder workshops (Kröger and Schäfer, 2016; Schwand and Steinhardt, 2016). For the peatland-use scenario assessment, the year 2040 was selected as the endpoint. The European Common Agricultural Policy (CAP), the national energy policy and regulations regarding the environment and resource protection, were designated as the key influencing factors for land use changes to peatlands in Northeast Germany. In addition, methods of value creation in rural areas and various life and consumption styles were considered as influencing factors for future peatland-use. Climatic trends and demographic changes were also considered but not varied between the two scenarios. For climate, increased temperature, less summer rain and a longer vegetation period were assumed for the federal state of Brandenburg (Gutzler et al., 2015); for demography, a negative population balance and an ageing population were assumed.

Table 2 shows the key characteristics of the analysed peatland-use scenario narratives in the *"Randow-Niederung"* in the county of *Uckermark*. One scenario—*PU1, "services for services"*—assumed the extensification of peatland-use and the decentralization of land management and the other—*PU2, "market determines usage"*—assumed the further intensification and centralization of land use systems. Within the DPSIR concept, these characteristics are the polarizing *(D)rivers* leading to different *(P)ressures* on the region-specific supply portfolio of LUFs, whose impacts on SD must be assessed.

Table 2
Key characteristics (Drivers and Pressures) of the two peatland-use scenarios in the *"Randow-Niederung"* in the county of *Uckermark* examined until 2040 (adapted from Schwand and Steinhardt, 2016). The polarizing *(D)rivers* are leading to different *(P)ressures* on peatland-use and thus influence the future supply portfolio of Land Use Functions.

Key characteristics		*Peatland-use Scenario PU1*	*Peatland-use Scenario PU2*
		"Services for services"	*"Market determines usage"*
(D)rivers:	**Polarizing key influencing factors** • Subsidies and regulations	**Common Agricultural Policy** • Public payments only for public goods and services derived from land use **Energy policy** • Energy transition by saving and efficiency; decentralized and emerging renewable energy-supply concepts **Environmental regulations** • High and integrated environmental restrictions	**Common Agricultural Policy** • Reduction of agricultural subsidies, market orientation **Energy policy** • Centralized and further based on fossil-energy concepts **Environmental regulations** • Low environmental protection and restrictions
(P)ressures:	**Ownership structure**	**Civil society engagement** • Land acquisition, inter alia, by foundations	**Land acquisition and management by large agricultural enterprises** • High land rents
	Water management	**Extensification of land use** • Successive uplift of groundwater levels: primarily involving preserving high groundwater levels (45 until 0 cm below top surface ground), water retention	**Intensification of land use** • Low groundwater levels (> 80 until 45 cm below top surface ground), drainage
	Persistent land use systems • in 2040	**Extensification of land use** • Extensive grassland (fresh and wet meadows), fresh and wet grazing (24 %)	**Intensification of land use** • Intensive grassland and meadows (15 %)
	Land use changes • New, additionally managed land use systems in 2040	**Extensification of land use** • Reeds (paludiculture; 45 %), short coppice rotations and high-quality woods (willow, alder; 15 %), wet grazing & water buffalos (8 %), abandonment of use (8 %), partial water retention areas	**Intensification of land use** • Arable land (55 %), short coppice rotations & high-quality woods (willow, alder; 25 %), abandonment of use (5 %)
	Value creation and operator models	**Decentralized organized operation models** • Extension of regional economy, tourism • Small and medium-sized agricultural enterprises • Public participation	**Centralized organized operation models, privatization** • Large agricultural enterprises • Large refineries in Schwedt and Prenzlau

The area percentages of the managed land use systems are estimations.

2.2.2. Region-specific Supply (Land use Functions) and Demand Portfolio (Land use Claims)

In Northeast Germany there exists no integrative and spatially explicit policy for peatlands management at the regional level aside from policy-specific overlaps. Thus, we used findings (region-specific sustainability-relevant topics per LUFs and corresponding land use claims derived from multi-level stakeholder strategies) from Hermanns et al. (2015) for this case study's *ex-ante* SIA of peatland-use scenarios in the *"Randow-Niederung"*. Next, we selected a long-list of indicators from the topics and land use claims related to the SD of the land management on the area-type peatlands in the county of *Uckermark* (Table S1). We used the indicators to assess the impacts of the peatland-use scenarios on the supply portfolio of region-specific LUFs.

However, to participatory assess the impacts of peatland-use scenarios on SD with stakeholders a selection of a manageable number of sustainability-relevant topics, indicators and land use claims was required. Thus, we conducted workshops with researchers at the scientific project level in October 2014 to select topics, indicators and land use claims for the LUFs. In three working groups for environmental, economic and social LUFs a short-list of one single indicator and sustainability-relevant topics for each LUF was derived out of the long-list. The goal of the selection was to choose the most important topics and indicators for each LUF and the regional SD of peatland-use in the county of *Uckermark*. By selecting one topic and indicator per LUF, the corresponding demand portfolio in terms of societal land use claims for the LUFs of peatlands in Northeast Germany were designated. After this workshop, we discussed the selected topics and indicators again with researchers in bilateral consultations and slightly modified them (Table S1), when found necessary in the final discussion of the researcher workshop.

2.2.3. Ex-ante sustainability impact assessment of peatland-use scenarios: confronting supply with demand

For the *ex-ante* SIA of the peatland-use scenarios in the *"Randow-Niederung"* we performed a participatory assessment workshop, in April 2015. For the two polarizing scenarios of extensive or intensive peatland-use, we analysed the extent to which changes in the region-specific supply portfolio of LUFs favoured or deviated from the demand portfolio of land use claims to calculate qualitative LUFs and land use claims budgets. As a result, the workshop captured local normative stakeholders' preferences that were not necessarily represented in the analysed strategy documents.

The 12 participants in the workshop included relevant stakeholders (e.g., representatives from institutions and associations related to nature conservation, water management and agriculture) and scientists in various research fields (e.g., hydrology and land use governance). These stakeholders were selected and invited by the project management board in accordance with an actor analysis conducted by Nölting and Daedlow (2012), whereby six main actor groups (water economists, farmers, public administrators, water and soil associations, environmental organizations, and policymakers at various governance levels) are identified. For each LUF, we asked one stakeholder to assume the role of a representative. If for any LUF a suitable stakeholder could not participate in the workshop, one researcher was asked to assume the corresponding role. This was done to cover all three dimensions of SD and each LUF equally and interdisciplinary (König et al., 2015). In each case, the roles were assigned such that they closely matched the expertise of the stakeholders and the researchers. These roles were categorized either at the level of national policy or at the level of the federal state of Brandenburg (Table S2).

Before starting our workshop, the participants received a background paper about the narrative description of the peatland-use scenarios; the *ex-ante* SIA approach of land use scenarios, the selected topics and indicators per LUFs and corresponding land use claims. At the beginning of the workshop, a scientist introduced the analytical framework to confront the region-specific supply with demand portfolios. Afterwards, (i) selected and specified LUFs (see Section 2.2) and land use claims were introduced, and (ii) scientists explained the main characteristics of the two polarizing peatland-use scenarios, and the assumed climatic and demographic trends in a presentation and on posters.

2.2.3.1. Perceived importance of the region-specific supply portfolio (land use functions): weighting. In the first round of the workshop, we asked the participants to evaluate the absolute importance of the single LUFs for the SD in the region on a scale from 0 (no perceived importance for regional SD) to 10 (very high perceived importance for regional SD). For this weighting, we asked the participants to consider the impacts on land use development in the entire *Uckermark* region. Afterwards, the workshop participants discussed the first weighting results.

2.2.3.2. Confronting supply (land use functions) with demand portfolio (land use claims): scored scenario impacts. In the second round, an assessment of the impacts of the peatland-use scenarios on the sustainability-relevant topics and indicators for the nine LUFs (preselected by researchers) was performed to assess the future supply portfolio of region-specific LUFs depending on the scenarios. This assessment was conducted on a scale from +3 (strong positive impacts) to - 3 (strong negative impacts) and we asked the workshop participants to consider the impacts of the scenarios on the selected land use claims. This way, the comparison of the impacts of the change in the supply portfolio of LUFs on the land use claims as benchmarks could be checked, and we identified sustainability gains and deficits. Next, we conducted another discussion of the impact assessment results (the scoring results) with the participants.

2.2.3.3. Scenario impact scores: weighted scenario impacts. In the third round, the scored scenario impacts on the LUFs were multiplied with the weighting of the respective LUFs (see above). Thus, stakeholders' perceived importance of the respective LUF could be considered in the impact assessment, allowing for interpretation of the sustainability impacts of the peatland-use scenarios and consideration of the specific weights for the single LUFs to obtain the weighted contribution for each dimension of SD.

The workshop ended with a scientist's final presentation of the summarized results of the *ex-ante* SIA, followed by an open discussion about the assessment results and their implications for options for action within land use and governance strategies.

3. Results

3.1. Region-specific supply (land use functions) and demand portfolio (land use claims)

Table 3 presents the region-specific supply portfolio of LUFs with the corresponding sustainability-relevant topics and indicators selected by the three interdisciplinary researcher groups (during the workshop at project level, in 2014) to assess the impacts of the peatland-use scenarios on SD. After the workshop at scientific project level, we slightly modified the indicators for ECO (4) (resource efficiency): gross value added per sector (agriculture, water economy and forestry) into area productivity: gross value added of the agricultural and forest area (Euro per hectare) and for ECO (6) (resource efficiency): profitability of infrastructure into profitability (revenues, investments and running costs) of water infrastructure (Table S1). By selecting the sustainability-relevant topics, the demand portfolio in terms of land use claims was designated as well (Table 3).

For the nine LUFs, the following sustainability-relevant topics, indicators and land use claims were selected. For detailed information about the area-specific and non-area specific SD targets for future land use that are condensed into land use claims and their NUTS and obligation levels, see Table S1.

The environmental LUFs provided the sustainability-relevant topics of water provision, habitat diversity and carbon and nutrient depots. The indicator - groundwater table - was chosen for the water supply. Groundwater table distance is a key indicator for peatland quality and development. High groundwater levels and rewetting can cause carbon sequestration and regrowth of the peat (Jarveoja et al., 2016). On used peatlands, a permanent loss of organic carbon is inevitable, but that loss can be reduced by high groundwater levels and soil-conserving grassland use. Identified land use claims affected by water provision in the region include the *"stabilization of landscape water balance"* and *"the rewetting of wetlands"* for ENV (1). Habitat diversity was chosen as a sustainability-relevant topic because near-natural peatlands are characterized by high habitat and structural diversity (Hillbricht-

Table 3
Selected supply and demand portfolio to confront region-specific supply (sustainability-relevant topics and indicators per LUF) with demand portfolios (land use claims) for the *ex-ante* SIA of peatland-use scenarios.

Region-specific Supply Portfolio			**Region-specific Demand Portfolio**
Land Use Functions (LUFs)	**Sustainability-relevant topics**	**Indicators**	**Land use Claims**
ENV* (1): Provision of abiotic resources	Water provision	Groundwater table	*"Stabilizing landscape water balance" → "Rewetting wetlands"*
ENV* (2): Provision of biotic resources	Habitat diversity	Area percentage of natural and near-natural biotopes [%]	*"Preserve biological diversity" → "Habitat protection"*
ENV* (3): Maintenance of ecosystem processes	Carbon and nutrient depot	Carbon and nutrient balance in the soil	*"Ensure and develop natural sinks" → "Carbon and nutrient depot"*
ECO* (4): Land-based production	Resource efficiency (profitability)	Area productivity: gross value added of the agricultural and forest area (euro per hectare)	*"Increase of resource and energy efficiency""Value creation in rural areas"*
ECO* (5): Non-land-based production	Resource efficiency (profitability)	Gross value added per sector (processing and marketing of agricultural and forest products, energy and tourism economy)	*"Increase of resource and energy efficiency""Value creation in rural areas"*
ECO* (6): Infrastructure	Resource efficiency (profitability)	Profitability (revenues, investments and maintenance costs) of water infrastructure	*"Needs-based infrastructure" → "Water management"*
SOC* (7): Participation	Rural development possibilities (value creation)	Diversity of companies	*"Value creation in rural areas""Diversification of the income possibilities"*
SOC* (8): Quality of life	Village infrastructure	Number of day-care centres, clubs, healthcare facilities (…)	*"Needs-based village infrastructure → Financing and spatial context"*
SOC* (9): Cultural and aesthetic values	Identification with the landscape	Percentage of persons who feel connected to the landscape	*"Strengthen regional identity"*

ENV*= environmental, ECO*= economic, SOC*= social.

Ilkowska, 2008). Thus, near-natural peatlands contribute to the maintenance of a diverse landscape. Although the vegetation is primarily dominated by sedge or reed species, it can also be interspersed with tree and shrub stocks or even be formed as a forest. Habitat diversity can be measured using the area percentage of natural and near-natural types of biotopes. *"Preserving biological diversity and habitat protection"*, which leads to habitat protection, is a major land use claim to provide biotic resources for ENV (2). Ensuring and developing natural sinks for carbon and nutrients is a major claim of ENV (3). Carbon and nutrient depots were chosen as sustainability-relevant topic because near-natural peatlands have an important function as natural sinks (Blackwell and Pilgrim, 2011). Changes in humus content caused by modified land use have a significant impact on the carbon balance, because more than twice as much carbon is stored in the soils than in the atmosphere (Curtin et al., 2000; Dao, 1998). The carbon and nutrient balance is a suitable indicator for this topic. As land use claims, *"ensuring and developing natural sinks"* are socially desirable.

Economic LUFs contained the sustainability-relevant topic of resource efficiency (profitability) for ECO (4), ECO (5) and ECO (6) with gross value added and profitability as indicators. Land-based production is based on wetlands' biomass production (crops, forest, livestock and game; Maltby and Acreman, 2011). Gross value added is derived from the total value of goods and services created in the production process (production value) minus the value of the human-managed process of consumed, processed or converted goods and services. The increase in gross value added indicates a more efficient use of resources. As land use claims for ECO (4) and ECO (5), *"value creation in rural areas and increase of resource and energy efficiency"* were identified. For the topic infrastructure, *"needs-based infrastructure and water management"* was highlighted as a region-specific land use claim. The indicator - profitability of water infrastructure (revenues, investments and maintenance costs) - can measure the efficiency of the water management of peatlands.

For the social LUFs, the adequate topics were rural development possibilities (value creation), village infrastructure and identification with the landscape. This is reasonable because the exploration and development of new economic fields in addition to traditional livelihoods increases rural value and secures income and employment. It can be the unique selling point of a region that can be measured by the indicator - diversity of companies. The identified land use claims for SOC (7) in the region were *"value creation in rural areas and the diversification of income possibilities"*. The presence of soft location factors (village infrastructure) in terms of, e.g., the number of day-care centres, clubs and healthcare centres in rural areas contributes to the improvement of SOC (8). At first sight, this indicator does not seem to be closely related to benefits derived from the use of the land. However, in the absence of other industries and services, as is the case in the test regions, researchers and stakeholders argued that this indicator would indeed reflect value creation from the use of the land. *"Needs-based village infrastructure in consideration of financing and the spatial context"* was identified as land use claim. Furthermore, the aesthetic and cultural valuation of a landscape is important because it is strongly related to personal factors. One indicator of landscape identity is the percentage of people who feel connected to the landscape. For SOC (9), the land use claim *"strengthen regional identity"* was detected.

3.2. Ex-ante sustainability impact assessment of peatland-use scenarios: confronting supply with demand

3.2.1. Perceived importance of the region-specific supply portfolio (land use functions): weighting

Table 4 shows the weighting results (means) of the participatory assessment workshop for the region-specific supply portfolio of nine LUFs. The perceived importance for the SD in the county of *Uckermark* of ENV (1) (water provision), ENV (2) (habitat richness), and SOC (7) (rural development possibilities) were weighted the highest by the

Table 4
Results of the participatory assessment workshop, in April 2015. Perceived importance (weighting) of the region-specific supply portfolio of LUFs. Confronting the changes of the supply of LUFs with the demand portfolio of land use claims to calculate qualitative LUFs and land use claims budgets and to identify sustainability gains and deficits.

Region-specific Supply Portfolio ofLand Use Functions (LUFs)	W*(means) =	*(I)mpacts* (means) of Scenario *PU1: "Services for services"*	*(I)mpacts* (means) of Scenario *PU2: "Market determines usage"*	Region-specificDemand Portfolio ofLand use claims
ENV* (1): Provision of abiotic resources	**8.0**	**+ 2.8**	**− 2.5**	*"Stabilization of landscape water balance / Rewetting of wetlands"*
ENV* (2): Provision of biotic resources	7.3	**+ 2.6**	**− 2.2**	*"Preserve biological diversity → habitat protection"*
ENV* (3): Maintenance of ecosystem processes	**6.6**	**+ 2.3**	**− 2.4**	*"Ensure and develop natural sinks → carbon and nutrient depot"*
ECO* (4): Land-based production	**6.3**	**− 1.3**	**+ 1.8**	*"Value creation in rural areas / Increased resource and energy efficiency"*
ECO* (5): Non-land based production	7.1	**+ 0.1**	**+ 1.2**	*"Increased resource and energy efficiency / Value creation in rural areas"*
ECO* (6): Infrastructure	**6.8**	**− 0.1**	**+ 0.7**	*"Needs-based infrastructure → Water management"*
SOC* (7): Participation	7.3	**+ 0.1**	**+ 0.3**	*"Value creation in rural areas / Diversification of income possibilities"*
SOC* (8): Quality of life	**5.8**	**− 0.4**	**− 0.2**	*"Needs-based village infrastructure → Financing"*
SOC* (9): Cultural and aesthetic values	**5.9**	**+ 0.8**	**− 0.9**	*"Strengthen regional identity"*

ENV*= environmental, ECO*= economic, SOC*= social. W*= weighting results (means) of perceived importance of the nine Land Use Functions for regional SD in the county of *Uckermark*. Positive impact=a societal land use claim is positively affected by a peatland-use scenario. Negative impact=a societal land use claim is negatively affected by a peatland-use scenario.

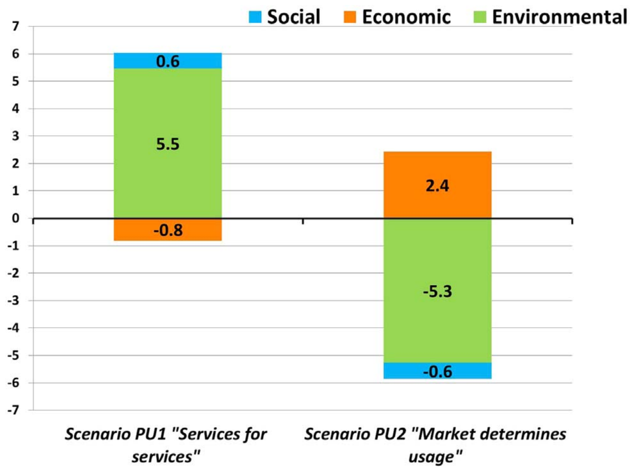

Fig. 3. Weighted contribution of the impacts of peatland-use scenarios to the three dimensions of sustainable development.

participants. The perceived importance of SOC (8) (village infrastructure), SOC (9) (identification with the landscape), and ECO (4) (profitability) were weighted the lowest.

3.2.2. Confronting supply (land use functions) with demand portfolio (land use claims): scored scenario impacts

Table 4 shows the workshop results of the scored impacts (means) of the two polarizing peatland-use scenarios on the future region-specific supply portfolio of LUFs as well. Through the *ex-ante* SIA of the peatland-use scenarios and by confronting the region-specific supply portfolio of LUFs with the demand portfolio of land use claims, we identified the following sustainability gains and deficits. These identified sustainability gains and deficits are illustrated by the plus and minus in Table 4.

The scenario of extensive peatland-use *PU1, "services for services"* had the most positive impacts on the land use claims. In this case, the supply of the environmental LUFs was very positively affected. With +2.8 for ENV (1) (water provision) the land use claims of *"stabilize landscape water balance"* and *"rewetting wetlands"* were supported. Furthermore, with +2.6 for ENV (2) (habitat richness), protecting near-natural and natural habitats for the land use claim *"preservation of biological diversity"* and with +2.3 for ENV (3) (matter depot) the land use claim *"ensure and develop natural sinks → matter depot"* were achieved. The economic LUFs of ECO (4) (resource efficiency), with - 1.3 and – 0.1 for ECO (6) (resource efficiency - water management) and the respective economic land use claims of *"value creation in rural areas and increased resource and energy efficiency"* were affected negatively. With +0.1 for ECO (5) (resource efficiency - profitability) and SOC (7) (rural development possibilities) and +0.8 for SOC (9) (regional identity) the economic land use claim of *"value creation in rural areas and increased resource and energy efficiency"* and the social land use claims of "*value creation in rural areas, diversification of income possibilities*" and *"strengthen regional identity"* were slightly positively achieved.

The scenario of intensive peatland-use *PU2, "market determines usage"* had stronger positive impacts on the topics and indicators related to three economic LUFs and respective land use claims. Consequently, with +1.8 for ECO (4) (resource efficiency) and +1.2 for ECO (5) (resource efficiency), the respective land use claims *"value creation in rural areas and increased resource and energy efficiency"* were achieved. For ECO (6) (resource efficiency) with +0.7, the land use claims *"need-orientation of infrastructure, two-sided water regulation"* were achieved. The environmental LUFs and respective land use claims, however, were all affected negatively (- 2.5 for ENV (1) (water provision); - 2.2 for ENV (2) (habitat diversity) and - 2.4 for ENV (3) (carbon and nutrient depot)). The social land use claims of *"value creation in the region and diversification of income possibilities"* were marginally affected positively with +0.3 for SOC (7) (rural development possibilities), and with – 0.9 for SOC (9) (regional identity) *"strengthen regional identity"* was affected negatively. With – 0.4 and – 0.1 for SOC (4) (village infrastructure), in both peatland-use scenarios, the land use claim *"needs-based village infrastructure"* was not achieved.

3.2.3. Scenario impact scores: weighted scenario impacts

Results of the weighted impact assessment of the peatland-use scenarios for each of the environmental, economic and social dimension of SD showed that the mainly environmental LUFs in scenario *PU1, "services for services",* achieved +5.5 out of a maximum of nine points; in scenario *PU2, "market determines usage,* the result was - 5.3 (Fig. 3). The economic and social impacts in this visualization for this scenario were low. With +2.4, only the weighted impact of scenario *PU2, "market determines usage"* on the mainly economic LUFs was high.

4. Discussion

4.1. Peatland-use scenarios and related trade-offs for sustainable development

With respect to future peatland-use in Northeast Germany, our participatory *ex-ante* SIA explored possible trade-offs between the societal demanded land use claims for biomass production, rural value creation and profitability of land use systems on peatlands and peatlands' sink (water and matter depot) and habitat functions. These results fit the findings of Maltby and Acreman (2011) regarding the trade-offs of ecosystem services provided by different land use systems on wetlands. However, according to Burkhard et al. (2012a), trade-offs often arise in multifunctional managed landscapes because the extension of one desired ecosystem service results in the decline of other ecosystem services. For example, sinking groundwater levels caused by intensified biomass production or fire clearing for agricultural value creation globally increase the stress on threatened valuable wetlands and endanger the preservation of biodiversity or natural carbon and nutrient sink functions (Maltby and Acreman, 2011). This seems to be the case for LUF and land use claims budgets at the regional level as well. Illustrating and minimizing these trade-offs in decision-making should therefore be a basic component of best-practice analytical approaches for the sustainability assessment of projects, planning and land use (Bond et al., 2012; Gibson, 2006).

The variance of the weighting was particularly high for ENV (3) (carbon and nutrient depot) and SOC (8) (village infrastructure). However, it was low for ENV (1) (water provision), ECO (5) (resource efficiency) and SOC (9) (identification with the landscape). The variance of the impact assessment of the peatland-use scenarios on the supply portfolio of LUFs was particularly high for ECO (4) (resource efficiency), ECO (5) (resource efficiency), ECO (6) (resource efficiency) and SOC (7) (rural development possibilities). The reason for this variance might be that it is difficult to assess the profitability of non-established value chains. One assessment workshop participant argued that ECO (4) (resource efficiency) was estimated too low, because peatlands are of high importance for value creation in rural areas in Brandenburg. In the discussion of the weighting, however, it was noted that peatlands are not key areas for agricultural production in Brandenburg.

4.2. Methodological potentials and limitations

Testing the analytical framework for *ex-ante* SIA (Hermanns et al., 2015) in a joint approach with researchers and stakeholders seemed to reveal that the FoPIA approach (Morris et al., 2011) practically can be modified to confront the changes of region-specific supply portfolios of

LUFs with demand portfolios of land use claims. The applied DPSIR-based framework therefore fits to analyse problem areas for the SD of land use and to operationalize the vision of SD at the regional level. The extended analytical framework enabled the joint determination of qualitative LUFs and land use claim budgets to note sustainability gains and deficits. The pitfall, however, relates to the limited reproducibility of such participatory approaches: the results of stakeholders preferences and assessments are valid for that particularly setting and are therefore not generalizable (König et al., 2013).

The concept of LUFs is well suited to conduct sustainability studies of future-oriented land use strategies' impacts on stakeholder targets in rural and semi-rural areas because stakeholder demands for all sustainability dimensions can be operationalized at various governance levels. By identifying societal land use claims, the manifold and potentially contradicting targets in multi-level stakeholder strategies can be condensed and used as qualitative benchmarks in an *ex-ante* SIA of land use scenarios. Regional stakeholder targets were used when area-specific targets for the LUFs were missing, because the analysed area-type peatlands is embedded within a spatial and socio-cultural context (Helming et al., 2011a) in Northeast Germany. Thus, the developed framework is particularly suitable for the *ex-ante* SIA of non-area concrete land use scenarios.

By only analysing societal land use demands, region-specific environmental restrictions (Moldan et al., 2012) in the *"Randow-Niederung"* and sustainability limits (Li et al., 2016; Morris et al., 2011; Paracchini et al., 2011) were not identified. To more strongly highlight multi-level stakeholder targets as benchmarks (Hacking and Guthrie, 2006; Pope et al., 2004) during the impact assessment — in contrast to the FoPIA approach according to Morris et al. (2011) — it is also possible to assess whether or not a land use claim is satisfied in cases when clear (quantitative) thresholds are available.

For the *ex-ante* SIA of land use scenarios at a regional level, it is necessary to identify multi-level, trans-sectoral and cross-policy indicators that are relevant for stakeholders in specific research sites. It was possible to link indicators to the identified land use claims to assess SD of land use. The topic and indicator selection for the nine LUFs and sustainable peatland-use in the *Uckermark* exposed indicators such as village infrastructure or profitability of the water management that, likewise the land use claims, not all are directly mapable. Despite this drawback, the strength is that they reflect multiple aspects of land use changes in human managed rural or semi-rural areas.

During the cross-strategy analysis, identified topics, indicators and land use claims must be discussed and refined with the help of researchers in order to reduce the complexity of these factors and derive a suitable basis for a participatory assessment workshop with stakeholders. This way, a co-learning activity with researchers and stakeholders was made possible. In addition, for an objectives-led and indicator-based SIA a clear normative interpretation of the condensed land use claims must be given. Finding suitable indicators to assess SD on actual area-types, for example, is complicated by moving policy targets (Petit and Frederiksen, 2011). As an alternative integrative scientific-derived SD targets, for example, applied for regional-level studies on the extension of bioenergy use in Germany could be used (Rösch et al., 2013; Grunwald and Rösch, 2011).

4.3. Putting ecosystem services into practice

In view of increasing scientific literature about ecosystem services, a proof of the concept through practical applications is required (Daily et al., 2009). However, evaluating ecosystem services and implementing this concept into practice is challenged by (i) the lack of relevant information for local scale decision making (Turner and Daily, 2008), (ii) the societal demand side has been neglected in most ecosystem service studies (Burkhard et al., 2012b), the lack of data on societal demands compared to data on production or costs (Ellis and Fisher, 1987), (iii) the lack of appropriate data for quantifying the individual services' supply and demand (Burkhard et al., 2012b), (iv) measuring social and cultural ecosystems services is particularly difficult (Satz et al., 2013; Chan et al., 2012), (v) the lack of balanced stakeholder participation into ecosystem service evaluation and decision making (Spangenberg et al., 2015).

Via our application of LUFs we used a derivation of the ecosystem service concept for the *ex-ante* SIA of peatland-use scenarios, thereby putting the general concept into practice. In particular, we demonstrated an approach to operationalize the societal demand side for ecosystem services. Thus, we overcame the challenges related to providing relevant information for local scale decision making and fixing the lack of data on the societal demand side. Social and cultural services were jointly evaluated by a balanced group of researchers and stakeholders at the local level. However, we did not quantified the individual services' supply and demand, and some of the selected LUFs indicators were rather conceptual and not directly mapable such as indicators used in the ecosystem services concept (Burkhard et al., 2012b; Maes et al., 2012). It was not the intention to quantitatively map ecosystem services because focus was laid on a qualitative estimation of the discrepancy between societal demands and supply of services created through the use of the land. We hypothesize that the achieved methodological progress in confronting land use supplies with demands for sustainability assessment of land use scenarios can be applied for ecosystem services as well. For this, the region-specific societal demand (ecosystem claims) for ecosystem services has to be determined within multi-level stakeholder strategies (e.g., stakeholder targets for non-provisioning services like water purification within different policies like the Water Framework Directive or provisioning services like food within the CAP as well as regional spatial planning concepts).

4.4. Solutions for sustainable development and peatland management

Operationalizing SD of land use and providing ecosystem services at the regional level is an adaptive multi-level, trans-sectoral and cross-policy governance task (Cook et al., 2016; Pahl-Wostl et al., 2010) that requires the transparent, accountable and minimized land use of trade-offs related to the triple bottom-line (Bond et al., 2012). Consequently, sustainable land management has the normative goal to obtain viable land use systems (Rückert-John et al., 2013). The extensification peatland-use scenario *PU1 "services for services"* revealed the most positive impacts on SD in the county of *Uckermark*. Whereby, the intensification peatlands-use scenario *PU2 "market determines usage"* revealed the most positive impacts on economic land use claims. The agricultural value created by maintaining the peat layer and the narrow definition of the main-use claim *1) sustainable intensification* from Garnett et al. (2013) only was achieved in scenario *PU1, "services for services"*. But, in this scenario the future created agricultural value was estimated as decreasing.

In addition to sectoral oriented targets for future land use, the analysed multi-level stakeholder strategies include many cross-cutting targets. The policy strategies highlight that as solutions for sustainable peatlands-use, coordinated land and water use intensities among the affected land use sectors are needed. The outcome of the international climate negotiation during the Conference of Parties (COP) 21 was the target to reduce global warming to 1.5 degree Celsius (Christoff, 2016). To achieve this, peatlands have a high importance, because of their potential to sequester carbon when being maintained in a near-natural state with high water table level. For local actors this superior policy target, however, is connected with economic trade-offs, because it interferes with intensive agricultural production. Thus, implications of the *ex-ante* SIA of peatlands-use scenario for policymakers are that environmental friendly peatlands-use systems need to be made more economically profitable through, e.g. payment schemes for such ecosystem services. To implement sustainable land use models into system solutions, it might be essential to revise policy fields and instruments such as the area payments without environmental requirements of the CAP, regional planning concepts and other institutional land use settings. After Nitsch et al. (2012) ensured grassland use, accompanying policy measures such as the application of cross compliance should prevent both conversions of peatlands to arable land and the loss of non-provisioning ecosystem services. Additionally, the protection and provision of natural sinks can be designed to be economically profitable via emissions trading and certificates. *Moorfutures* is an example of the application of the Payments for Ecosystem Services approach in Germany (Meyer et al., 2015).

Furthermore, the participation of regional stakeholders and decision-makers in the *ex-ante* SIA of land use scenarios and development of strategies for sustainable land use is necessary to achieve regional SD targets because those actors will determine future land use (König et al., 2015). However, the implementation of stakeholders' strategies in consensual decision-making strongly depends upon the degree of participation (Lange et al., 2015). For regional actors, the land management is the adjusting screw to adapt to shifting institutional settings. Thus, implications of the *ex-ante* SIA of peatlands-use scenarios for practitioners are that site-adapted land use systems with adjusted water management are necessary because of the heterogeneity of Brandenburg's peatlands (e.g., ownership structure, land use systems, different peat layers and groundwater levels). But, to be economically profitable these land use systems need governmental support. The site-specific peatlands-use intensity, however, is influenced by the overall use of peatlands in a region and the land use of the surrounding areas as well.

5. Conclusions

Land use changes influence the SD of rural and semi-rural areas by altering the supply of ecosystem services and multifunctional land use systems at a regional level. To develop sustainable land use strategies, their *ex-ante* SIA requires integrative and spatially explicit approaches. We concluded that the application of an adapted FoPIA approach can confront the changes of the region-specific supply portfolios of LUFs with demand portfolios of land use claims. Environmental Policy Integration included manifold stakeholder SD targets at various governance levels into an *ex-ante* SIA. The frame analysis of stakeholder targets condensed region-specific land use claims as benchmarks for the supply of LUFs. These benchmarks were used to assess the impacts of peatlands-use scenarios on SD and explore possible trade-offs. Hence, we successfully linked the regional endogenous conditions of the analysed area-type peatlands with exogenous land use drivers and demands of stakeholders, and we captured decision-relevant indicators at a regional level. By creating an integrative *ex-ante* SIA of land use scenarios we improved the understanding of the required regionalizing of stakeholder targets for future land use this matches the gaps related to needed analytical methods to assess SD of land use. Findings revealed that implementing multifunctional land use systems on peatlands would lead to the greatest possible realization of the identified societal land use claims in Northeast Germany. To support the supply of ecosystem services, multifunctional land use systems and the supply of public goods and services at the regional level, it seems practical to extend the Payments for Ecosystem Services approach.

As a future research activity, a mapping and quantitative calculation of the LUFs and land use claims budgets as applied by Burkhard et al. (2012b) to ecosystem services can be conducted. Transferred to the ecosystem services concept, our analytical approach can be used for the joint determination of qualitative region-specific supply and demand budgets for ecosystems services. Moreover, for the integrative and objectives-led *ex-ante* SIA of land use scenarios it might be beneficial to apply the identified societal land use claims as benchmarks for the supply of LUFs instead of targets exclusively related to the triple bottom-line. For this, the peatlands-use scenario impacts on the selected side-use claims have to be matched with the corresponding six main-use claims (Hermanns et al., 2015).

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ecoser.2017.02.002.

References

Beland Lindahl, K., 2008. Frame Analysis, Place Perceptions and the Politics of Natural Resource Management: Exploring a Forest Policy Controversy in Sweden (Doctoral Thesis) 2008. Swedish University of Agricultural Sciences, Uppsala, 60, Acta Universitatis agriculturae Sueciae.
Blackwell, M.S.A., Pilgrim, E.S., 2011. Ecosystem services delivered by small-scale wetlands. Hydrol. Sci. J. 56, 1467–1484.
Bond, A., Morrison-Saunders, A., Pope, J., 2012. Sustainability assessment: the state of the art. Impact Assess. Proj. Apprais. 30, 53–62.
Burkhard, B., de Groot, R., Costanza, R., Seppelt, R., Jørgensen, S.E., Potschin, M., 2012a. Solutions for sustaining natural capital and ecosystem services. Ecol. Indic. 21, 1–6.
Burkhard, B., Kroll, F., Nedkov, S., Müller, F., 2012b. Mapping ecosystem service supply, demand and budgets. Ecol. Indic. 21, 17–29.
Burkhard, B., Hotes, S., Wiggering, H., 2016. Agro(eco)system services—supply and demand from fields to society. Land 5, 9.
Butterfield, B.J., Camhi, A.L., Rubin, R.L., Schwalm, C.R., 2016. Chapter five – tradeoffs and compatibilities among ecosystem services: biological, physical and economic drivers of multifunctionality. Adv. Ecol. Res. 54, 207–243.
Chan, K.M.A., Guerry, A.D., Balvanera, P., Klain, S., Satterfield, T., Basurto, X., Bostrom, A., Chuenpagdee, R., Gould, R., Halpern, B.S., Hannahs, N., Levine, J., Norton, B., Ruckelshaus, M., Russell, R., Tam, J., Woodside, U., 2012. Where are cultural and social in ecosystem services? A framework for constructive engagement. Bioscience 62, 744–756.
Christoff, P., 2016. The promissory note: COP 21 and the paris climate agreement. Environ. Polit. 25, 765–787.
Cook, D.C., Kristensen, N.P., Liu, S., 2016. Coordinated service provision in payment for ecosystem service schemes through adaptive governance. Ecosyst. Serv. 19, 103–108.
Curtin, D., Wang, H., Selles, F., McConkey, B.G., Campbell, C.A., 2000. Tillage effects on carbon fluxes in continuous wheat and fallow–wheat rotations. Soil Sci. Soc. Am. J. 64, 2080–2086.
Daily, G.C., Polasky, S., Goldstein, J., Kareiva, P.M., Mooney, H.A., Pejchar, L., Ricketts, T.H., Salzman, J., Shallenberger, R., 2009. Ecosystem services in decision-making: time to deliver. Front. Ecol. Environ. 7, 21–28.
Dao, T.H., 1998. Tillage and crop residue effects on carbon dioxide evolution and carbon storage in a paleustoll. Soil Sci. Soc. Am. J. 62, 250–256.
De Groot, R.S., Alkemade, R., Braat, L., Hein, L., Willemen, L., 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecol. Complex. 7, 260–272.
Ellis, G.M., Fisher, A.C., 1987. Valuing the environment as input. J. Environ. Manag. 25, 149–156.
Garnett, T., Appleby, M.C., Balmford, A., Bateman, I.J., Benton, T.G., Bloomer, P., Burlingame, B., Dawkins, M., Dolan, L., Fraser, D., Herrero, M., Hoffmann, I., Smith, P., Thornton, P.K., Toulmin, C., Vermeulen, S.J., Godfray, H.C.J., 2013. Sustainable intensification in agriculture: premises and policies. Science 341, 33–34.
Geneletti, D., 2011. Reasons and options for integrating ecosystem services in strategic environmental assessment of spatial planning. Int. J. Biodivers. Sci. Ecosyst. Serv. Manag. 7, 143–149.
Germer, S., Kaiser, K., Bens, O., Hüttl, R.F., 2011. Water balance changes and responses of ecosystems and society in the Berlin-Brandenburg region – a review. Die Erde

142, 65–95.
Gibson, R.B., 2006. Sustainability assessment: basic components of a practical approach. Impact Assess. Proj. Apprais. 24, 170–182.
Grunwald, A., Rösch, C., 2011. Sustainability assessment of energy technologies: towards an integrative framework. Energy Sustain. Soc. 1, 1–10.
Gutzler, C., Helming, K., Balla, D., Dannowski, R., Deumlich, D., Glemnitz, M., Knierim, A., Mirschel, W., Nendel, C., Paul, C., Sieber, S., Stachow, U., Starick, A., Wieland, R., Wurbs, A., Zander, P., 2015. Agricultural land use changes—a scenario-based sustainability impact assessment for Brandenburg, Germany. Ecol. Indic. 48, 505–517.
Hacking, T., Guthrie, P., 2006. Sustainable development objectives in impact assessment: why are they needed and where do they come from? J. Environ. Assess. Pol. Manag. 08, 341–371.
Hacking, T., Guthrie, P., 2008. A framework for clarifying the meaning of triple bottom-line, integrated, and sustainability assessment. Environ. Impact Assess. Rev. 28, 73–89.
Hansen, J.W., 1996. Is agricultural sustainability a useful concept? Agric. Syst. 50, 117–143.
Harvey, M., Pilgrim, S., 2011. The new competition for land: food, energy, and climate change. Food Pol. 36 (Suppl. 1), S40–S51.
Helming, K., Pérez-Soba, M., Tabbush, P. (Eds.), 2008. Sustainability Impact Assessment of Land Use Changes. Springer, Berlin, Heidelberg, 507.
Helming, K., Diehl, K., Bach, H., Dilly, O., König, B., Kuhlman, T., Pérez-Soba, M., Sieber, S., Tabbush, P., Tscherning, K., Wascher, D., Wiggering, H., 2011a. Ex ante impact assessment of policies affecting land use, Part A: analytical framework. Ecol. Soc. 16, 29.
Helming, K., Diehl, K., Kuhlman, T., Jansson, T., Verburg, P.H., Bakker, M., Pérez-Soba, M., Jones, L., Verkerk, P.J., Tabbush, P., Morris, J.B., Drillet, Z., Farrington, J., LeMouël, P., Zagame, P., Stuczynski, T., Siebielec, G., Sieber, S., Wiggering, H., 2011b. Ex ante impact assessment of policies affecting land use, Part B: application of the analytical framework. Ecol. Soc. 16, 29.
Hermanns, T., Helming, K., Schmidt, K., König, H.J., Faust, H., 2015. Stakeholder strategies for sustainability impact assessment of land use scenarios: analytical framework and identifying land use claims. Land 4, 778–806.
Hillbricht-Ilkowska, A., 2008. The mid-European agricultural landscape: catchment-scale links between hydrology and ecology in mosaic Lakeland regions, In: Ecohydrology: Processes, Models and Case Studies: An Approach to the Sustainable Management of Water Resources. CAB International: Wallingford, UK, pp. 187–206.
Jarveoja, J., Peichl, M., Maddison, M., Soosaar, K., Vellak, K., Karofeld, E., Teemusk, A., Mander, U., 2016. Impact of water table level on annual carbon and greenhouse gas balances of a restored peat extraction area. Biogeosciences 13 (9), 2637–2651.
Jordan, A., Lenschow, A., 2010. Environmental policy integration: a state of the art review. Environ. Pol. Gov. 20, 147–158.
König, H.J., Uthes, S., Schuler, J., Zhen, L., Purushothaman, S., Suarma, U., Sghaier, M., Makokha, S., Helming, K., Sieber, S., Chen, L., Brouwer, F., Morris, J., Wiggering, H., 2013. Regional impact assessment of land use scenarios in developing countries using the FoPIA approach: findings from five case studies. J. Environ. Manag. 127, S56–S64, Supplement.
König, H.J., Podhora, A., Zhen, L., Helming, K., Yan, H., Du, B., Wübbeke, J., Wang, C., Klinger, J., Chen, C., Uthes, S., 2015. Knowledge brokerage for impact assessment of land use scenarios in inner Mongolia, China: extending and testing the FoPIA approach. Sustainability 7, 5027–5049.
Kok, K., Biggs, R., Zurek, M., 2007. Methods for developing multiscale participatory scenarios: insights from Southern Africa and Europe. Ecol. Soc. 13, 8.
Kopfmüller, J., Brandl, V., Jörissen, J., Paetau, M., Banse, G., Coenen, R., Grunwald, A., 2001. Nachhaltige Entwicklung Integrativ Betrachtet - Konstitutive Elemente, Regeln, Indikatoren. Sigma ed., Berlin, p. 432.
Kröger, M., Schäfer, M., 2016. Scenario development as a tool for interdisciplinary integration processes in sustainable land use research. Futures 84, 64–81.
Lange, A., Siebert, R., Barkmann, T., 2015. Sustainability in land management: an analysis of stakeholder perceptions in rural northern Germany. Sustainability, 8.
Larondelle, N., Lauf, S., 2016. Balancing demand and supply of multiple urban ecosystem services on different spatial scales. Ecosyst. Serv. 22, 18–31.
Li, Q., Amjath-Babu, T.S., Zander, P., Müller, K., 2016. Sustainability of smallholder agriculture in semi-arid areas under land set-aside programs: a case study from China's loess plateau. Sustainability, 8.
Maes, J., Egoh, B., Willemen, L., Liquete, C., Vihervaara, P., Schägner, J.P., Grizzetti, B., Drakou, E.G., Notte, A.L., Zulian, G., Bouraoui, F., Luisa Paracchini, M., Braat, L., Bidoglio, G., 2012. Mapping ecosystem services for policy support and decision making in the European Union. Ecosyst. Serv. 1, 31–39.
Maltby, E., Acreman, M.C., 2011. Ecosystem services of wetlands: pathfinder for a new paradigm. Hydrol. Sci. J. 56, 1341–1359.
Mander, Ü., Helming, K., Wiggering, H., 2007. Multifunctional land use. In: Mander, Ü., Wiggering, H., Helming, K. (Eds.), Multifunctional Land Use: Meeting Future Demands for Landscape Goods and Services. Springer, Berlin, Heidelberg, 1–13.
Meyer, C., Reutter, M., Matzdorf, B., Sattler, C., Schomers, S., 2015. Design rules for successful governmental payments for ecosystem services: taking agri-environmental measures in Germany as an example. J. Environ. Manag. 157, 146–159.
Moldan, B., Janoušková, S., Hák, T., 2012. How to understand and measure environmental sustainability: indicators and targets. Ecol. Indic. 17, 4–13.
Morris, J.B., Tassone, V., de Groot, R., Camileri, M., Moncada, S., 2011. A framework for participatory impact assessment: involving stakeholders in European policy making, a case study of land use change in malta. Ecol. Soc. 16, 12.
Müller, F., Burkhard, B., 2007. An ecosystem based framework to link landscape structures, functions and services. In: Mander, Ü., Wiggering, H., Helming, K. (Eds.), Multifunctional Land Use – Meeting Future Demands for Landscape Goods and Services. Springer, Berlin, Heidelberg, 37–64.
Nitsch, H., Osterburg, B., Roggendorf, W., Laggner, B., 2012. Cross compliance and the protection of grassland – Illustrative analyses of land use transitions between permanent grassland and arable land in German regions. Land Use Pol. 29, 440–448.
Nölting, B., Daedlow, K., 2012. Einblick in die Akteurslandschaft zum Wasser- und Landmanagement in Brandenburg und Berlin. ZALF, Müncheberg, Germany.
O'Farrell, P.J., Anderson, P.M.L., 2010. Sustainable multifunctional landscapes: a review to implementation. Curr. Opin. Environ. Sustain. 2, 59–65.
Olsson, J.A., Bockstaller, C., Stapleton, L.M., Ewert, F., Knapen, R., Therond, O., Geniaux, G., Bellon, S., Correira, T.P., Turpin, N., Bezlepkina, I., 2009. A goal oriented indicator framework to support integrated assessment of new policies for agri-environmental systems. Environ. Sci. Pol. 12, 562–572.
Organization for Economic Co-operation and Development (OECD), 1993. OECD core set of indicators for environmental performance reviews: a synthesis report. organisation for economic Co-operation development, Group on Environmental Performance. organisation for economic Co-operation development, Group on the state of the environment. Environ. Monogr. 83, 35.
Pahl-Wostl, C., Holtz, G., Kastens, B., Knieper, C., 2010. Analyzing complex water governance regimes: the Management and Transition Framework. Environ. Sci. Pol. 13, 571–581.
Palacios-Agundez, I., Fernández de Manuel, B., Rodríguez-Loinaz, G., Peña, L., Ametzaga-Arregi, I., Alday, J.G., Casado-Arzuaga, I., Madariaga, I., Arana, X., Onaindia, M., 2014. Integrating stakeholders' demands and scientific knowledge on ecosystem services in landscape planning. Landsc. Ecol. 29, 1423–1433.
Paracchini, M.L., Pacini, C., Jones, M.L.M., Pérez-Soba, M., 2011. An aggregation framework to link indicators associated with multifunctional land use to the stakeholder evaluation of policy options. Ecol. Indic. 11, 71–80.
Pérez-Soba, M., Petit, S., Jones, L., Bertrand, N., Briquel, V., Omodei-Zorini, L., Contini, C., Helming, K., Farrington, J.H., Tinacci Mossello, M., Wascher, D., Kienast, F., De Groot, R., 2008. Land use functions: a multifunctionality approach to assess the impact of land use changes on land use sustainability. In: Helming, K., Pérez-Soba, M., Tabbush, P. (Eds.), Sustainability Impact Assessment of Land Use Changes.. Springer, Berlin, Heidelberg, 375–404.
Pope, J., Annandale, D., Morrison-Saunders, A., 2004. Conceptualising sustainability assessment. Environ. Impact Asses. Rev. 24, 595–616.
Pintér, L., Hardi, P., Martinuzzi, A., Hall, J., 2012. Bellagio stamp: principles for sustainability assessment and measurement. Ecol. Indic. 17, 20–28.
Petit, S., Frederiksen, P., 2011. Modelling land use change impacts for sustainability assessment. Ecol. Indic. 11, 1–3.
Rametsteiner, E., Pülzl, H., Olsson, J.A., Frederiksen, P., 2011. Sustainability indicator development—science or political negotiation? Ecol. Indic. 11, 61–70.
Reed, M.S., Graves, A., Dandy, N., Posthumus, H., Hubacek, K., Morris, J., Prell, C., Quinn, C.H., Stringer, L.C., 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. J. Environ. Manag. 90, 1933–1949.
Rösch, C., Aust, C., Jörissen, J., 2013. Envisioning the sustainability of the production of short rotation coppice on grassland. Energy Sustain. Soc. 3, 1–17.
Rounsevell, M.D.A., Pedroli, B., Erb, K.H., Gramberger, M., Busck, A.G., Haberl, H., Kristensen, S., Kuemmerle, T., Lavorel, S., Lindner, M., Lotze-Campen, H., Metzger, M.J., Murray-Rust, D., Popp, A., Pérez-Soba, M., Reenberg, A., Vadineanu, A., Verburg, P.H., Wolfslehner, B., 2012. Challenges for land system science. Land Use Pol. 29, 899–910.
Rückert-John, J., Nolting, B., Schäfer, M., Moss, T., Steinhardt, U., Lischeid, G., 2013. Verständnis Nachhaltigen Landmanagements im Verbundprojekt ELaN. In: Weith, T., Besendörfer, C., Gaasch, N., Kaiser, D.B., Müller, K., Repp, A., Rogga, S., Strauß, C., Zscheischler, J. (Eds.), Nachhaltiges Landmanagment: Was ist das?. ZALF, Müncheberg, Germany.
Satz, D., Gould, R.K., 2013. The challenges of incorporating cultural ecosystem services into environmental assessment. Amibo 42, 675–684.
Schößer, B., Helming, K., Wiggering, H., 2010. Assessing land use change impacts – a comparison of the SENSOR land use function approach with other frameworks. J. Land Use Sci. 5, 159–178.
Schwand, I., Steinhardt, U., 2016. Landnutzungsszenarien - ein Gestaltungsprozess. Die Entwicklung von Szenarien als ein Prozess mit Unsicherheiten, Expertenwissen und Zukunftsideen auf dem Weg zu einer nachhaltigen Landnutzung. ZALF, Müncheberg, Germany.
Söderberg, C., Eckerberg, K., 2013. Rising policy conflicts in Europe over bioenergy and forestry. For. Pol. Econ. 33, 112–119.
Spangenberg, J.H., Görg, C., Settele, J., 2015. Stakeholder involvement in ESS research and governance: between conceptual ambition and practical experiences - risks, challenges and tested tools. Ecosyst. Serv. 16, 201–211.
Turner, R.K., Daily, G.C., 2008. The ecosystem services framework and natural capital conservation. Environ. Resour. Econ. 39, 25–35.
Wiggering, H., Dalchow, C., Glemnitz, M., Helming, K., Müller, K., Schultz, A., Stachow, U., Zander, P., 2006. Indicators for multifunctional land use—Linking socio-economic requirements with landscape potentials. Ecol. Indic. 6, 238–249.
Wilson, G.A., 2007. Multifunctional agriculture: a transition theory perspective. ⟨http://dx.doi.org/10.1079/9781845932565.0000⟩.
World Commission on Environment and Development (WCED), 1987. Our Common Future. Oxford University Press, Oxford, UK.
Zanten, B.T., Verburg, P.H., Espinosa, M., Gomez-y-Paloma, S., Galimberti, G., Kantelhardt, J., Kapfer, M., Lefebvre, M., Manrique, R., Piorr, A., Raggi, M., Schaller, L., Targetti, S., Zasada, I., Viaggi, D., 2013. European agricultural landscapes, common agricultural policy and ecosystem services: a review. Agron. Sustain. Dev. 34, 309–325.