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Research article

UNESCO biosphere reserves show demand for multifunctional agriculture

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ABSTRACT

Sustainable landscape management of protected areas in UNESCO-biosphere reserves (BR) has become an increasingly important topic for academics and environmental practitioners, yet it remains unclear how this can be operationalized in actual regional circumstances. To achieve positive and measurable sustainability impacts, effective BR management on the ground requires supplementary methods to conceive the unique territorial, political, economic and social characteristics of each case while also considering the needs and visions of different stakeholder groups.

In this study, we used the Framework for Participatory Impact Assessment (FoPIA) to assess future projections of current land management strategies and possible alternatives in five BR in Germany. The FoPIA method helped identify major differences in the regional BR contexts, including defining the sustainability problem and sustainability challenges. It also proved suitable for fostering stakeholder dialog with regard to current and future sustainable land use management, particularly for the BR transition zones. Our results predict multiple negative impacts resulting from of a continuation of current practices, which are compared against the assessed outcomes of alternative multifunctional pathways. We use these findings to discuss recommendations and challenges for sustainable management of biosphere reserves, the potential of implementing the FoPIA in BR, and perspectives for further research needs.

1. Introduction

Land use changes driven by climate change and social factors are significant threats to sustainable land use and the functionality of ecosystems around the world (Foley et al., 2005). As a consequence, protected areas for nature conservation are increasingly threatened. At least 50% of the protected areas of nearly three-quarters of the world's countries are under intense human pressure, including threats from mining, road construction, or conversion to intensive forestry or agriculture (Jones et al., 2018).

The need to prevent the decline of natural habitats while at the same time expanding the sustainable provision of ecosystem services requires the implementation of innovative conservation and management schemes that integrate economic, environmental and social objectives (Villalobos, 2000). The United Nations Educational, Scientific and Cultural Organization (UNESCO)-biosphere reserves (BR) for sustainable development (SD) were introduced as role models for linking socio-economic and cultural perspectives to conservation and to offer a comprehensive approach to nature and landscape protection (Ishwaran et al., 2008). The guidelines for BR management explicitly state the objective to simultaneously promote economic, ecological and cultural goals for sustainable development in the conservation of landscapes (BMU, 2018). To achieve this, BR employ a zonation approach that differentiates between a core zone dedicated solely to nature conservation, a maintenance zone dedicated to landscape conservation and a transition zone dedicated to socioeconomic objectives, such as sustainable agriculture, tourism and marketing (Van Cuong et al., 2017).

Moreover, BR legislation has introduced stakeholder participation as a key element to offer new opportunities for participatory conservation. However, as it is difficult to integrate participation into BR management on the ground and measuring its impacts on SD is not straightforward, effective implementation of participation is often lacking behind initial

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objectives (Stoll-Kleemann et al., 2010). In fact, an increasing body of literature questions whether the participation paradigm shift has truly occurred and whether sustainable outcomes on land use and management of BRs have been achieved (Stoll-Kleemann et al., 2010; Giordano et al., 2013; Bridgewater, 2016; Taggart-Hodge and Schoon, 2016).

In this article, we present results from a study in Germany, in which the impacts of current and future land use scenarios for BR were elaborated and assessed together with regional stakeholders. The aim of the work was to provide a holistic perspective on the main dynamics and regional sustainability challenges and to derive recommendations for sustainable land management strategies. Five different BR across Germany were selected as case study areas to represent varying management challenges. The Framework for Participatory Impact Assessment (FoPIA) (Morris et al., 2011) was used as a diagnostic assessment tool.

Specifically, we aimed to answer the following research questions:

1. Are current BR management practices in Germany successful in terms of integrating the objectives of agricultural production with ecological and social objectives for balanced sustainable development?
2. What alternative BR land management scenarios can be envisioned, and how would they affect economic, social and environmental sustainability outcomes?
3. Is the chosen method (FoPIA) a suitable tool to contribute to improved stakeholder engagement in the land use management of BR?

2. Materials and methods

2.1. Case study areas

Germany has a total of 18 biosphere reserves that cover 3.7% of the country's territory, 16 of which have the status of UNESCO biosphere reserves, which means that they underwent an objective certification process based on defined structural and functional criteria (BMU, 2018). The first BR in Germany was designated in 1979 (BR Thuringian Forest),

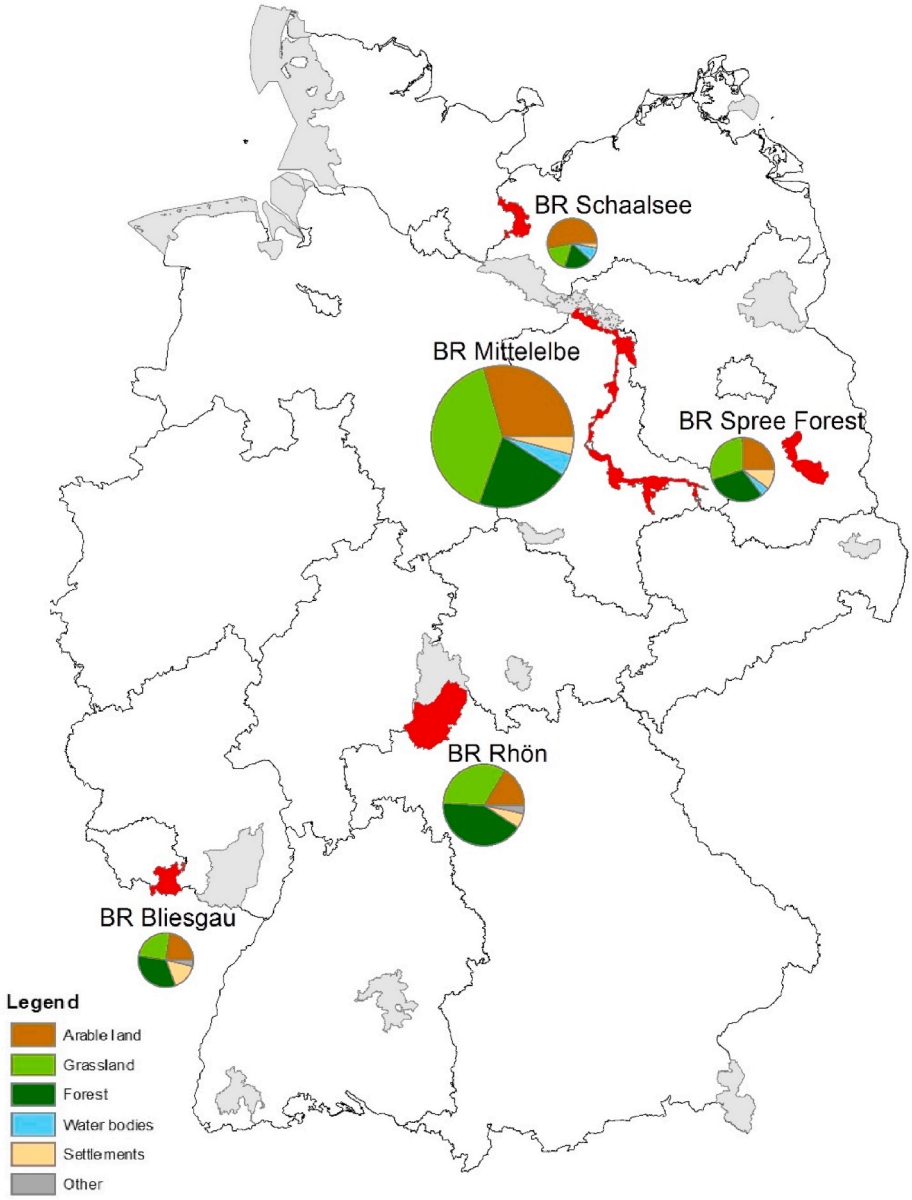

Fig. 1. Location, size and land use types of the five biosphere reserves considered in this study (red shaded; gray shaded: locations of all biosphere reserves in Germany).

and the latest was designated in 2017 (BR Black Forest).

All BR represent important German landscape types with a characteristic diversity of habitats, fauna and flora and are mostly cultural landscapes of particular importance for the preservation of biological diversity (DRL, 2010). Their special ecological value originates from economic use, for example, through grazing or viticulture, and can only be preserved through economic use. The German biosphere reserves are primarily located in rural areas and are promoted as future concepts for these areas; additionally, they often constitute popular holiday destinations and local recreational areas. The aging population and outmigration (DRL, 2010), climate change and Germany's renewable energy transition, which provides incentives for intensified land use through energy crops, create major challenges for the BRs, which require novel management concepts and the involvement of all relevant actors (BMU, 2018).

For this study on future BR management scenarios, five BR in Germany along a north–south gradient (Fig. 1) were selected with the aim of covering a variety of landscape types and socioeconomic conditions (Table 1).

The environmental characteristics (e.g., climate or water balance) of the investigated BR differ due to their specific spatial and historical conditions (Table 1). For example, the BR *Rhön* and *Schaalsee* are located along the former inner-German border, and their nature benefited from several decades of extensive use during Germany's separation. The BR *Bliesgau* is characterized by a small-structured landscape and a close interconnection between rural and urban areas. The BR *Spree Forest* is a vast inland delta of the river "Spree", characterized by wetland forests and a wide system of natural river branches and canals that play a central role in the traditional agricultural land use system in this region since the fields can only be accessed with boats via canals. The BR *Mittelelbe* covers parts of the large Elbe River and consists of large grassland areas and some remaining floodplain forests. In terms of land use, in all cases, agriculture is the most important land use activity in the transition area (Fig. 1; arable land and grassland).

2.2. The Framework for Participatory Impact Assessment (FoPIA)

To elaborate and assess current and future development options for the five BR, we made use of the Framework for Participatory Impact Assessment (FoPIA) (Morris et al., 2011; König et al., 2013, 2017, 2021). The FoPIA is a structured set of research steps (see Table 2) that can be used to guide the discussion of diverse stakeholders in the development and evaluation of alternative land management scenarios while following five typical steps of sustainability impact assessment: identify the problem, define objectives, develop scenarios, assess impacts, and compare scenarios (Hamidov et al., 2022). The major outcomes of the FoPIA are a set of alternative land use scenarios including a trend continuation and their assessed impacts on regional economic, social and environmental sustainability criteria.

The criteria for selecting this approach were its participatory nature, which appeared to be promising for involving different BR stakeholder groups, its focus on all three sustainability dimensions, which aligned well with the overall approach and mission of BR, and its adaptability, as demonstrated by a variety of case studies around the globe (König et al., 2013, 2017).

The principle research steps of the FoPIA are shown in Table 2, which were also followed in our implementation of the FoPIA in the five BR, including (I) a preparation phase during which a regional context analysis is carried out, land use scenarios are drafted and sustainability impact assessment criteria and indicators are selected, (II) a stakeholder

Table 1
Case study characteristics and attributes of regional land management in the five BRs.

BR Name/Federal State	Protection target	Landscape types	Regional land use problem	Agricultural situation	Regional Management strategies
BR Rhön (Bavaria) 184,939 ha	Maintain montane and submontane humid grasslands	Low mountain range in the center of Germany; diverse landscape: high plateau, extensive grasslands and high moors	Structural depletion of landscape elements, profitability of full-time large-scale farms, grassland degradation, decline of animal husbandry, outmigration, aging population	Approximately 2.500 agricultural companies are located in the area, of which 81% are managed part-time; no wind energy	Reinforcing usage and funding, especially for contractual nature conservation for grassland usage
BR Bliesgau (Saarland) 36,152 ha	Maintain orchard species-rich orchid meadows and old beech forests	North: mainly forested variegated limestone South: open land shaped by shell limestone with semiarid grasslands, orchids and woodruff-beech forests	Structural change in agriculture, land abandonment, competition with other land use purposes, lack of perspectives for young agricultural population, larger enterprises taking over vacant and valuable areas	57% decline of agricultural enterprises (>2 ha) from 1979 to 2001, selective intensification of agricultural management, increase in larger enterprises	Organic farming, livestock farming, grassland funding, tourism, professionalization of regional and direct marketing, high-quality regional products and services
BR Schaalsee (Mecklenburg-Vorpommern) 30,257 ha	Maintain close-to-natural forests, bogs and lakes; areas for breeding, molting, resting and overwintering ground for water- and shorebirds	Baltic beech forests representing the biotope type of "deciduous green forests" in northern Central Europe, surrounding the lake "Schaalsee"	Overall ecological trend in the agricultural development but also land use intensification in the last decades with negative ecological impacts, improvement of the water quality of the *Schaalsee* and surrounding water bodies	Agriculturally dominated landscape: 70% of total area. Agriculture has played an important role in the regional development and landscape for decades.	Crop rotation, organic farming, grassland management, precision agriculture
BR Spree Forest (Brandenburg) 47,485 ha	Maintain wetlands and wetland meadows, riverside meadows and rivers	Extensive lowland area, historic cultural landscape, natural branching and canals of the river "Spree"; floodplain and moor landscape	Lack of professional (specialized) workers, outflow of young people, demographic change	Over 70% of the agricultural area is organically certified; traditional agriculture is labor intensive (often unclear succession)	Organic farming, operational diversification, regional marketing, renaturation, nature-compatible tourism (e.g., water tourism)
BR Mittelelbe (Saxony-Anhalt) 125,510 ha	Maintain river habitats, alluvial grassland, oxbows, deciduous and mixed forests	Unique floodplain biotope of the river "Elbe"	Sustainable land use is impacted by the alteration of the water dynamics in the floodplain area of the Elbe river	Approximately 46% of the area in the examined floodplain area[a] constitutes grassland	Agricultural grassland usage, forestry usage, summer dike slotting

[a] Between the Elbe river (kilometer 232–236 from the Elbe) and the flood protection dike.

Table 2
Sequences of the FoPIA method.

FoPIA phase	Assessment steps	Activities	Who	Time
Preparation (begins approx. half a year before workshop)		Literature and material survey and analysis Interviews and meetings with experts Stakeholder selection and invitation Preparation of workshop material	R	Several weeks
Stakeholder workshop (1–2 days)	Step 1: Scenario development	General introduction and explanation of the goals and sequence of the FoPIA Self-introduction of the stakeholders (icebreaker) Presentation of the status quo of the regional land use situation Elaboration of scenario assumptions	M S S (M)	2–3 h
	Step 2: Specification of the sustainability context	Presentation of land use functions Paper-based weighing of importance of LUF (2 rounds), presentation of result after each round (diagrams, tables), moderated discussion	M S (M)	2–3 h
	Step 3: Impact Assessment	Paper-based assessment of scenario impacts Presentation of weighted scenario results, discussion of policy implications and consequences for regional sustainable development Evaluation of the workshop	S (M) M, S	3–4 h
Evaluation		Processing and overall evaluation of results Report/article writing	R	Several weeks

Notes: M = Moderator, R = Researchers, S = Stakeholders.

workshop during which sustainability criteria are weighted and scenario impacts on the these criteria are assessed by regional stakeholders, followed by an evaluation of the assessed scenarios and of the FoPIA approach itself, and (III) an evaluation phase during which the results are processed, analyzed and documented.

2.2.1. Preparation phase

2.2.1.1. Development of land use scenarios. During the FoPIA preparation phase, we performed desk work (literature survey) and conducted expert interviews to identify the major forces driving the development in the five BR and possible management options.

The general questions asked in the expert interviews in each BR were as follows:

- What are central developments/main dynamics affecting agriculture in the transition zone?
- What are the regional sustainability problems? (related to enterprises and land use)
- Which factors control agricultural land use? (main drivers)

The literature analysis and interviews revealed that the major driving forces in our BR case studies originate mainly from the policy level, especially agricultural and nature conservation policy (Table 3), along with economic development and demographic trends. Demographic change projections forecast an ongoing decline and aging of the population in all five BR. Some BR also highlighted the importance of technological progress for land management, which referred primarily to novel manure application techniques and smart and *precision farming* (see Table 3). In the BR *Middle Elbe,* flood protection and the water management of the Elbe river were determined to be additional specific driving forces.

Based on the identified drivers and relevant management options, initially three regional land use scenarios with a time horizon of ten to 13 years in the future were drafted (see Table 3). Only in the case of BR Rhön, four scenarios were developed. However, the forth scenario was not included in this comparison as assumptions and results were similar to the trend scenario for this BR. Each scenario was characterized by means of different features (such as shares of land use, number of agricultural enterprises or tourist offers in the region) through preferably plausible assumptions and outlined in tabular form.

The trend scenarios were comparable among the five BR, as the assumed continuation of current regional trends in land use was investigated in all five BR (Table 3), while the alternative scenarios were region-specific and, thus, only partially comparable.

2.2.1.2. Specification of the sustainability context. The next step included the definition of relevant sustainability criteria, the selection of assessment indicators, and the participatory weighting of each criterion (Table 4). As regional sustainability criteria, we built on the Land Use Functions (LUFs) concept by Pérez-Soba et al. (2008), which consists of nine LUFs (three economic LUFs, three social LUFs, three environmental LUFs), and adapted it to the regional context and BR setting. LUFs represent relevant land use-related goods and services within rural areas that are primarily affected by land use changes (see Table 4).

For each LUF, we selected an operational assessment indicator (Table 4). For the selection, indicator sets used in comparable scenario assessment studies (Morris et al., 2011; König et al., 2013; Hermanns et al., 2015) were considered while also taking into account local expert knowledge, mainly from the staff of the BR administrative bodies.

2.2.1.3. Stakeholder selection. The stakeholders involved in the FoPIA workshops are organizations or individuals who are either directly affected by policy decisions (e.g., farmers, other land users) or are responsible for policy design or implementation (e.g., practitioners, planners, decision-makers). In close cooperation with the respective BR administrative bodies, we selected and invited relevant stakeholders to participate in this study. Table 5 shows the allocation of workshop participants to different stakeholder groups (agriculture and forestry, nature conservation, water, processing and marketing, tourism and culture, administration and biosphere reserves and regional development). The number of participants in the regional workshops ranged between 10 and 18 stakeholders. The stakeholder selection criteria were "regional affectedness" and "thematic affiliation" to preferably cover different action fields of the land use in the BRs. Due to the high importance of the topic "water" in the BR *Spree Forest* and *Middle Elbe,* representatives of this stakeholder group were present in these two cases.

2.2.2. Stakeholder workshops including (III) evaluation phase

Regional stakeholder workshops (1–2 days) were held for all five BR. The research steps carried out during the workshops included (i) an elaboration and agreement on the final land use scenarios, (ii) a stakeholder-based weighting of the selected sustainability criteria (LUFs), and (iii) a participatory assessment of the scenario impacts, including an evaluation of the scenario results and the chosen approach.

Table 3
Overview of the land use scenarios for the five biosphere reserves.

Area and target year	Trend scenario A	Management scenario B	Management scenario C
BR Rhön (Bavaria) 2025	**"Extrapolated trend"**: Fewer and larger farms, declining livestock numbers, narrow crop rotations, moderate increase in organic farms, mixed grassland trends, nonregional food processing	**"Priority ecological":** more organic farming, reduced farm structural change, greater crop variety with legumes, reduced grassland intensity, nonregional food processing	**"Priority conventional-regional"**: extended financial support for farm investments and diversification, strengthened regional marketing, more livestock, increased grassland intensity, more regional food processing
BR Bliesgau 2026	**"Extrapolated trend":** Increase in settlements, fewer and larger farms, grassland abandonment, livestock numbers low and declining, yet more horses, growing tourism but not well-connected to agriculture	"**Regionally targeted grassland funding**" with a considerable increase in extensive cattle (Grassland conservation through extensive use)	Collaborative regional direct marketing ("**Culinary farming**") leading to new value chains, more organic farming & a slight increase in livestock numbers
BR Schaalsee 2026	**"Extrapolated trend":** Ongoing agricultural phosphorus emissions threatening lake systems, conventional agriculture dominant and intensifying, decline in dairy production, regional marketing potential not materialized	Focus on "**Organic farming and regional marketing**", more landscape elements & connectivity, reduced phosphorus problem, promotion of rare crop and livestock varieties, sustainable tourism (lake), strengthened regional marketing	Model region "**Agriculture 4.0**": region-wide focus on digitalization and precision farming to reduce agricultural externalities, improve animal welfare and meet consumer demands, higher transparency, new knowledge, narrow crop rotations
BR Spree Forest 2026	**"Extrapolated trend":** Land use constant, slightly declining farm numbers, high share of organic farms, tourism increasing, regional marketing successful but stagnating, financial support (agricultural policy, contractual nature conservation) declining	"**Agriculture 4.0**": expansion of precision farming with reduced use of fertilizers and pesticides, automated and steered production processes, tourism and organic farming stable, decline in traditional agriculture	"**Renaturation & regional value creation**": strict renaturation, restoration and care measures in the transition zone, diversification of farms including tourism, further increase of organic farming, cultural landscape tax raised from tourists to finance landscape care and new machinery
BR Mittelelbe 2023	**"Extrapolated trend":** Ongoing riverbed erosion worsened by climate change, flooding all five years, land use supported through agri-environment payments, decline in seasonally wet grassland, increase in regional marketing and tourism	"**Summer dike slotting**", special floodplain renaturation project (climate change adaptation), annual flooding, grassland use less certain, bike trails affected, increased disaster risk perception, landscape attractiveness increasing, risk: chemical contamination of floodplain area	Creation of a "**Flood protection polder**": (technical flood protection), additional and higher dikes, flooding frequency: all 25 years, feeling of safety, loss of traditional floodplain area, worsened riverbed erosion, reduced landscape attractiveness

Each workshop followed a similar procedure. After a general introduction and self-introduction of the stakeholders, the draft scenarios from the preparation phase were presented and discussed, allowing for final adjustments and a shared understanding. For the stakeholder-based criteria weighting, the participants were presented with detailed descriptions of the nine sustainability criteria (LUFs, Table 4) and indicators. Also in this step stakeholder-based adjustments were possible, explaining slight differences among the five BR (Table 4). A large poster of the assessment matrix (LUFs vs. criteria) was presented; each participant received adhesive dots in the color used to designate its stakeholder group and was asked to estimate the importance of every LUF for SD in the region on a scale from 0 until 10 by placing a dot on the respective cross point of each number and LUF. This step delivered a participant-specific weighting, which was aggregated for groups of stakeholders (group mean values) and the entire BR (overall weighted mean).

For the scenario impact assessment, each workshop participant received an assessment sheet for each land use scenario (3–4 sheets in total, depending on the number of land use scenarios in each BR). The sheets showed the impact assessment matrix with the nine LUF criteria and corresponding indicators (Table 4). Each participant was asked to assess the impact of the respective scenario on the LUF criteria using values from −3 to +3 (with 0 = no effects; −1/+1 = little negative or positive effects; −2/+2 = highly negative or positive effects; −3/+3 = extremely negative or positive effects). Additionally, space was provided to allow participants to justify their assessments.

The workshop evaluation step included a presentation and discussion of the results of the previous steps (LUF weighting, scenario impact assessment and weighted impact assessment), followed by a general discussion of the results and of the FoPIA method. For the overall presentation of the scenarios for the three sustainability dimensions (economic, social, and environmental), (i) the LUF weights and (ii) scenario impact scores were aggregated. For example, the weights and scores for the three economic LUFs (Table 4) were used to generate an overall value for the economic dimension, and the same approach was pursued for the social and environmental dimensions. This enabled a comparison and ranking of the different scenarios, based on which potential implications for sustainable land use and decision support could be discussed (König et al., 2013). In addition, the workshop participants were asked to provide feedback on the FoPIA approach, focusing on how the stakeholders perceived the method, its usefulness for BR management and possible perspectives for future use in the BR context.

2.2.3. Evaluation phase

The third phase in a FoPIA application is the scientific evaluation of the previous steps, including comparative studies, e.g., between different BR and stakeholder groups, the processing of results and the report or article writing.

3. Results

The FoPIA outputs included the developed land use scenarios (Table 3), the mean weighting results for the single LUFs (Table 6), the assessed scenario impacts (Fig. 2), and their weighted aggregation to sustainability dimensions (Table 7).

3.1. BR Rhön

Among the nine LUFs, SOC(1) *Work* was weighted highest followed by ECO(1) *Production* and SOC(2) *Quality of life*. ENV(2) *Water* was rated highest among the environmental LUFs, while the two economic LUFs ECO(2) *Processing* and ECO(3) *Tourism* ranked lowest (Table 6). Aggregating the LUFs into the three sustainability dimensions, social functions were rated highest, followed by environmental functions and, finally, economic functions.

Trend scenario A (*"extrapolated trend"*) was assessed to have

Table 4
LUFs and corresponding assessment indicators in the five biosphere reserves.

Dimension and land use function		Description	Indicators	BR Rhön	BR Bliesgau	BR Schaalsee	BR Spree Forest	BR Mittelelbe
ECO(1)	**Production**	Regional value creation from agriculture (Primary production & processing)	Value creation from primary agricultural production	**x**	**x**		**x**	
			Value creation from regional agricultural production (primary & processed)			**x**		
			Value creation from primary agricultural and forestry production					x
ECO(2)	**Processing**	Regional value creation through processing of agricultural products	Value creation from the processing chain	**x**	**x**		**x**	
			Value creation from *regional* processing			**x**		**x**
ECO(3)	**Tourism**	Regional value creation through expansion and development of tourism	Value creation from tourism	**x**	**x**	**x**	**x**	**x**
SOC(1)	**Work**	Providing regional working places, which are directly or indirectly connected with agriculture	Regional attachment of workers	**x**				
			Attachment of workers to agriculture		**x**	**x**		
			Number of employees				**x**	
			Jobs in the region					**x**
SOC(2)	**Quality of life**	Recreational value of the landscape for residents and visitors	Attractiveness of the landscape (for recreation)	**x**	**x**	**x**	**x**	
			Flood risk perception					**x**
SOC(3)	**Culture**	Importance and appreciation of the landscape as a cultural asset	Identification with the landscape (as home/a cultural asset)	**x**	**x**	**x**		**x**
			Area of the traditional cultural landscape				**x**	
ENV(1)	**Soil**	Securing healthy soil and soil fertility	Soil fertility	**x**		**x**		**x**
			Ensuring natural soil processes		**x**		**x**	
ENV(2)	**Water**	Securing high water quality of groundwater and surface water	Water quality	**x**	**x**	**x**	**x**	
			Water supply in the floodplain area					**x**
ENV(3)	**Biodiversity**	Providing habitats for native animals and plants	Habitat diversity	**x**	**x**	**x**	**x**	**x**

Table 5
Regional impact assessment workshops: stakeholders (type/n).

Biosphere reserve	Agriculture and forestry	Nature conservation	Water management	Processing and marketing	Tourism and culture	Administration of biosphere reserves and regional development	n total
BR Rhön	4	1	/	2	/	3	**10**
BR Bliesgau	4	3	/	/	1	4	**12**
BR Schaalsee	8	/	/	/	/	7	**15**
BR Spree Forest	1	7	1	1	5	/	**18**
BR Mittelelbe	3	4	2	/	2	1	**12**

Table 6
Mean weighting result for each Land Use Function (LUF).

BR	Economic LUFs			Social LUFs			Environmental LUFs		
	Production	Processing	Tourism	Work	Quality of life	Culture	Soil	Water	Biodiversity
Bliesgau	8.1	8.7	7.8	7.9	9.0	7.6	7.8	7.3	7.1
Mittelelbe	7.1	8.7	8.0	8.7	8.3	7.3	8.9	9.3	9.2
Rhön	7.7	4.4	4.1	8.4	7.7	4.8	6.6	7.4	5.4
Schaalsee	9.5	8.3	7.9	8.5	9.5	8.1	9.5	9.3	9.5
Spreewald	7.8	7.7	7.8	8.6	8.8	7.3	8.4	9.5	9.0

negative impacts, especially for the environmental LUFs. The only LUF that was positively assessed was ECO(1) *Primary production*, as the assumed enlargement and specialization of agricultural enterprises in this scenario was estimated to lead to more efficient production. Management scenario B *„priority ecological"*, showed positive trends for all nine LUFs, while scenario C, *"priority conventional-regional"* showed positive impacts for all economic LUFs, SOC(1) *Work* and SOC(3) *Culture* but was rated negatively with regard to the remaining LUFs (Fig. 2). Overall, scenario B showed the highest weighted impact in total (+7.1 compared to A: 3.9, C: +2.0 and D: +1.5), indicating that this scenario could be the most appropriate future scenario for the BR *Rhön* (Table 7).

3.2. BR Bliesgau

The social and economic dimensions were of higher importance to the stakeholders of this BR than the environmental dimension (Table 6). Individually, SOC (2) *Quality of life* was ranked highest, followed by ECO (2) *Processing* and ECO(1) *Primary production*.

Trend scenario A was assessed to have negative impacts on all LUFs, except for LUF ECO(3) *Tourism*, suggesting a strong need for alternative

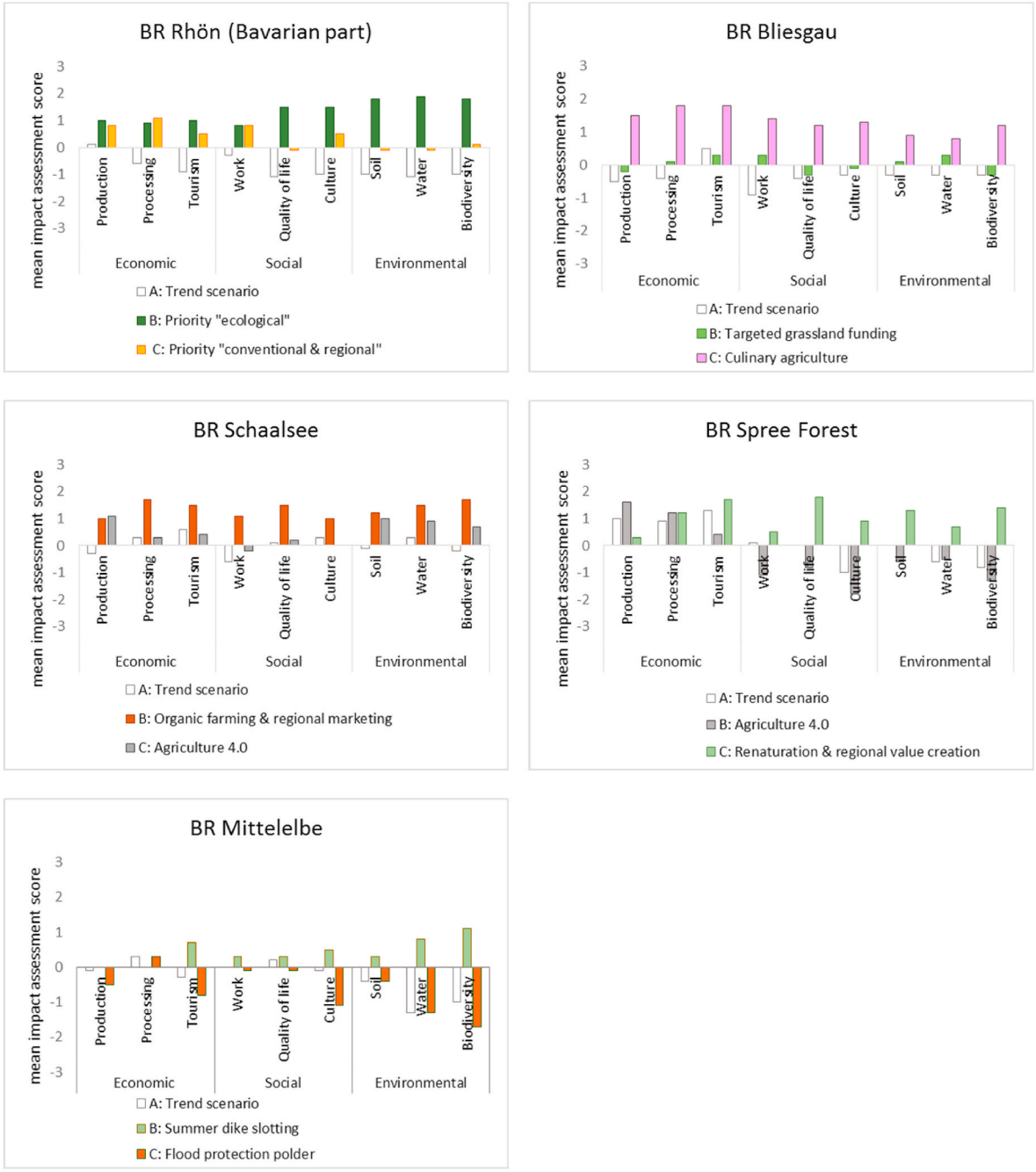

Fig. 2. Stakeholder-assessed impacts of the land use scenarios in the five biosphere reserves.

management options to realize sustainable development. Scenario B, "*regionally targeted grassland* funding", was assessed to have only small impacts across all LUFs.

Scenario C, "*culinary agriculture*", which focused on collaborative and objective regional direct marketing, however, was expected to have positive impacts on all LUFs, especially those of the economic dimension (Fig. 2). Overall, scenario C also had the highest weighted impact in total (Table 7: +9.5 compared to A: 2.2 and B: +0.2), indicating that this scenario could have the highest SD potential for the BR *Bliesgau*.

3.3. BR Schaalsee

For the participants of the assessment workshop in the BR *Schaalsee* LUFs of the environmental dimension were of highest priority, followed by social and economic land use functions (Table 6).

The only dimension benefiting slightly from trend scenario A was the economic one (+0.6), while the effect on the environmental dimension was neutral and social functions were negatively affected (−0.2). Management scenario B, "*organic farming and regional marketing*", showed high positive values for all three dimensions (economic: +3.5, social: +3.1, environment: +4.1). Scenario C, "*model region agriculture 4.0*", received positive values for the economic (+1.5) and environment (+2.5) dimensions, while the effect on the social function was expected to be negligible. Although all management scenarios showed a positive total weighted impact, scenario B (+10.7) was the most appropriate one, as it greatly exceeded the other two scenarios (A: +0.4 and C: 4.0) (Table 7).

Table 7
Weighted scenario impact assessment results per sustainability dimension.

Region	Land use scenarios	Weighted impact assessment			
		wECO	wSOC	wENV	wTotal
BR Rhön	A: Trend scenario	−0.4	−1.6	−1.9	**−3.9**
	B: Priority ecological	+1.3	+2.4	+3.4	**+7.1**
	C: Priority conventional & regional	+1.1	+1.1	−0.2	**+2.0**
BR Bliesgau	A: Trend scenario	−0.3	−1.2	−0.7	**−2.2**
	B: Regionally targeted grassland funding	+0.2	−0.1	+0.1	**+0.2**
	C: Culinary agriculture	+4.2	+3.2	+2.1	**+9.5**
BR Schaalsee	A: Trend scenario	+0,6	−0,2	0,0	**+0.4**
	B: Organic farming & regional marketing	+3.5	+3.1	+4.1	**+10.7**
	C: Agriculture 4.0	+1.5	0.0	+2.5	**+4.0**
BR Spree Forest	A: Trend scenario	+2.4	−0.7	−1.2	**+0.5**
	B: Agriculture 4.0	+2.5	−3.0	−2.1	**−2.6**
	C: Renaturation & regional value creation	+2.5	+2.6	+3.1	**+8.2**
BR Mittelelbe	A: Trend scenario	−0.1	+0.1	−2.4	**−2.4**
	B: Summer dike slotting	+0.5	+0.9	+2.1	**+3.5**
	C: Flood protection polder	−0.9	−1.0	−3.1	**−5.0**

Bold: Highest rated scenario for each BR.

3.4. BR Spree Forest

In this BR, the two highest rated LUFs were in the environmental dimension, as follows: ENV(2) *Water* (mean value 9.5) and ENV(3) *Biodiversity*, followed by SOC(2) *Quality of life* (Table 6).

Trend scenario A achieved a slightly positive overall assessment score (+0.5), yet the two highly weighted LUFs, i.e., ENV(2) *Water* (−0.6) and ENV(3) *Biodiversity* (−0.8), were negatively impacted. Scenario B, "*agriculture 4.0",* which assumes increasing mechanization and automation of agriculture, was expected to benefit primarily economic LUFs (mean + 1.1) and lead to negative values for social (mean −1.2) and environmental (mean −0.8) LUFs. Management scenario C, "*renaturation and regional value creation*", was the most promising scenario for the BR *Spree Forest* as it achieved positive impact assessment scores for all nine LUFs (Fig. 2). Additionally, in terms of the total weighted impact, scenario C scored highest (+8.2 compared to A: +0.5 and B: 2.4) (Table 7).

3.5. BR Mittelelbe

The three LUFs in the environmental dimension were rated the highest in the BR *Mittelelbe*, followed by social and economic functions (Table 6).

ECO(2) *Processing* (+0.3) and SOC(2) *Quality of life* (+0.2) were the only LUFs that showed positive values in trend scenario A, while the environmental LUFs showed high negative values. In contrast, management scenario B, "*summer dike slotting 2030",* was estimated to be neutral or positive for all LUFs, with especially high values in the environmental dimension (wENV: +2.4). Management scenario C, "*flood protection polder 2030"*, was estimated to have a negative impact on all three dimensions (Fig. 2). These results indicate that scenario B is the preferable management strategy, as it had the only positive value and the highest weighted impact assessment value (+3.5 compared to A: 2.4 and C: 5.0) (Table 7).

3.6. Comparison of the BR results

The current case study shows that the priorities of the different LUFs varied among the five BRs, which reflects both regional sustainability problems and landscape characteristics of the BRs (Table 6).

For the impact assessment, similar patterns were observed in the five BRs, as follows: 1) the trend scenarios had small to moderate impacts on the LUFs, and the impacts were mostly negative, especially for the environmental dimension, 2) the scenarios that were based on organic agriculture and regional value-added creation were rated positively without exception, and 3) the management strategy *"agriculture 4.0"* was only rated positively with regard to the economic dimension (BRs *Schaalsee*, *Spree Forest*).

4. Discussion

4.1. Challenges and recommendations for sustainable land management in BRs

The current study confirmed that the impacts of the trend scenarios in the five BR were predominantly negative, while the assessment of alternative management scenarios varied in the five BR depending on their strategic focus. Scenarios with a primarily economic focus received negative to slightly positive values, while management scenarios with an environmental focus showed the highest positive impact scores in all five BRs without exception.

In all five BRs, the workshop participants stressed the importance of organic farming for the BR transition area, as organic farming was viewed as a multifunctional means to reduce negative agricultural impacts and maintain the BR's cultural landscapes while also strengthening regional value chains. The agricultural modernization scenario ("agriculture 4.0") followed closely in terms of assessed overall impacts. However, its perception was mixed, as this scenario is primarily reducing negative agricultural externalities through more targeted application of fertilizers and pesticides without providing solutions for the ongoing structural changes of the BR.

Rather narrow scenarios dedicated to single objectives, such as grassland management in the *Bliesgau* BR or flood protection in the *Mittelelbe* BR, are rather unsuitable approaches for future BR management, as the associated trade-offs with other sustainability dimensions, e.g., local employment, are insufficiently accounted for. This is in line with Mander et al. (2007) and O'Farrell and Anderson (2010), who argue that multifunctional land use systems have the greatest potential to realize the SD of land management in BR. LUFs are provided at the landscape level, and the agricultural sector plays an important role; therefore, approaches and funding to encourage collaboration between farmers should be extended to improve landscape-level preservation in BR (Plieninger et al. 2012). Collaborative approaches for agricultural payment schemes have been implemented in several EU member states, which provide a broad range of benefits, e.g., in social learning, managing and coordinating sustainable land use at the landscape scale

(Prager, 2015; Westerink et al., 2017, 2020), particularly in multifunctional landscapes at the local level (García-Martín et al., 2016). Council regulation No. 1305/2013 obliges the EU member states to implement article 35 of ('collaboration'), which offers new opportunities for collaborative approaches in BRs.

Agriculture fulfills many important tasks in addition to food production, including landscape conservation and scenery aesthetics, soil function preservation (cleaning, fertility, etc.), biodiversity protection, water and wind erosion prevention, as well as serving as an income source (Helming et al., 2011; Lefebvre et al., 2015); it is therefore a key factor for the sustainable development of BRs.

An example is the study of the UNESCO BR in Slovakia, where abandonment of agriculture led to a loss of traditional landscape and soil degradation (Masny and Zauskova, 2014). Recently, there have also been approaches to create local food consumption networks and promote traditional agriculture in the region through branding and effective marketing (Knaus et al., 2017). The Röhn BR, one of the cases in this study, had been facing serious farm abandonment and outflow of the young generation in the 1980s but underwent a positive transformation in the 1990s by re-evaluating its less intensive, regionally linked and diversified traditional agriculture (Knickel, 2001). Such local networks creating a direct link and greater trust between producers and consumers can be implemented by certifying local products with a label guaranteeing their origin and by promoting sustainable production (Boesch et al., 2008).

Important for sustainable development and the socioeconomic and environmental functionality of BR is to take the landscape context of the existing land use types, i.e., diversity and spatial configurations, into consideration. Because each landscape exhibits a specific appearance (Lothian, 1999), which in BR ought to represent unique values, maintaining land use diversity not only preserves the options for future developments but also preserves the related uniqueness and attractiveness of the region and can serve as a selling point for regional commodities, including tourism and regional agricultural products (Knickel and Maréchal, 2018).

The use of modern agricultural technologies, e.g., *precision farming*, does not contradict this, but can even help to achieve these goals in an appropriate manner (Schieffer and Dillon, 2015; Steward et al., 2019). This was also perceived as having high potential in our study.

One goal of BRs is sustainable tourism, avoiding mass tourism and the related detrimental environmental impact, which could also be observed in some study areas. Overtourism is an ongoing field of research (Høegh-Guldberg et al., 2021) and may be curbed by upgrading less-used areas. An example in our study was the *Nordumfluter,* one of the countless side arms of the *Spree* river, near *Zauche* (BR Spree Forest), where the somewhat increased utilization of water thus far less used for touristic purposes could lead to a desirable discharge of the neighboring overcrowded running waters.

Another obstacle in realizing alternative sustainable management strategies is a lack of knowledge for applying case-specific measures. As an example, in the case of the *summer dike slotting* in the *Mittelelbe* BR, hydrological modeling and an in-depth professional examination are required to consider flood probabilities and estimate water distribution in the area according to the high-water levels of the Elbe River. Careful planning is recommended, as without sufficient knowledge and consideration of the local situation, a well-meant strategy can result in disadvantages for the local residents. For example, in the case of the *Mulde* river in the state of Saxony, there were more than 200 pleas from affected owners and farmers objecting to plans to slot an old dike (Bobbe et al., 2003).

Implementing sustainable land use strategies that promote the socioeconomic and environmental functionality of BR will profit from (i) cooperation between stakeholders of different land use sectors, (ii) integration of land use innovations for land use practices, e.g., for the key factor agriculture, and taking into account its social and economic implications, iii) involvement of stakeholders and experts and fostering the exchange between them to co-create informed decisions for specific projects, which affect land use in a broad sense, and (iv) development and implementation of appropriate instruments for the previous three strategies.

4.2. Potentials and challenges of using FoPIA for BR impact assessment

It is vital to know the characteristics of the respective land use system, including the complex feedbacks between drivers and impacts, to develop an effective land management strategy (Nesheim et al., 2014), and participatory approaches have great potential to contribute to decision-making toward achieving regional SD (De Groot et al., 2010). Similarly, participatory processes are important contributors to inclusive land use management, especially in BRs. Studies have shown that the lack of community participation can lead to conflicts between local inhabitants and management authorities, but this can be mitigated by involving local people in the planning and assessment of management strategies (Rao et al., 2003). Wissen et al. (2008), for example, applied 3D visualization tools at a stakeholder workshop in the Entlebuch BR in Switzerland and found that all models helped stakeholders to understand the problems in the BR by simplifying and visualizing complex issues. A study in the buffer zone of a Man and Biosphere Reserve in Chiapas, Mexico actively involved farmers in the process of agroecosystem design and identified factors and patterns of communal decision-making by applying an in-depth analysis of game strategies deployed by participants (Speelman et al., 2014). The increase in studies that aim to promote and improve participatory land use management methods and strategies indicates that the involvement of local residents is essential for the sustainable development of BR.

By combining these two factors, i.e., impact assessment and normative stakeholder values, FoPIA visualizes the trade-offs between different scenario impacts to support well-informed and normative decisions (Gibson, 2006). This has been proven by the results of this study, where trade-offs between several management strategy impacts on the economic, social and environmental dimensions were revealed.

The remaining analytical challenges for sustainability assessment are the matching of the supply of and societal demand for LUFs (Hermanns et al., 2015; Uthes and Matzdorf, 2016), as well as selecting regionally relevant and operational indicators (Rametsteiner et al., 2011). Further challenges for impact assessment are the integration of quantitative information about the state of environmental and socioeconomic features. For a more detailed analysis of trade-offs among different stakeholder groups, FoPIA can also be combined with the Social-ecological framework of ecosystem services and disservices (SEEDS)-Framework (König et al., 2021).

5. Conclusions

The current participatory assessment of land use scenarios in five biosphere reserves in Germany confirmed that the socioeconomic and environmental functionality characteristics of the five biosphere reserves are challenged by similar trends. A nonadjusted continuation of current management practices is likely to have negative impacts on the future sustainable development of BR.

Alternative and complementary land use scenarios, often including the promotion of organic agriculture, have the potential to improve the future perspectives of BR, which may be positive for the environment and the maintenance of the cultural landscape, while also strengthening regional value chains. However, changing or refocusing BR strategies requires formats for adequate and objective stakeholder participation, which enable the exchange of different views and needs that could eventually result in discourse coalitions among different actor groups and thus alter management concepts and practices.

The FoPIA approach for elaborating and assessing alternative land use scenarios proved useful for this task. This could be an orientation for the implementation of similar cases where policy-makers, academics,

environmental practitioners and local stakeholders work together to translate global BR principles into locally adapted and context-specific practices. The involvement of the local community and the implementation of participatory methods are therefore indispensable to assess the impacts of land use scenarios on sustainable development in biosphere reserves.

Credit author statement

Hannes Jochen König: Conceptualization, Methodology, Investigation, Formal analysis, Writing. Sandra Uthes: Formal analysis, Writing, Visualization. Emu Ostermann-Miyashita: Writing, Visualization. Luca Eufemia: Formal analysis, Writing. Karoline Hemminger: Formal analysis, Writing. Till Hermanns: Investigation, Formal analysis, Writing. Claudia Bethwell: Investigation, Writing, Funding aquisition. Ulrich Stachow: Writing, Funding acquisition. Katharina Helming: Methodology, Writing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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