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Combining policy analyses, exploratory scenarios, and integrated modelling to assess land use policy options

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1. Introduction

The future of the natural environment is highly uncertain and there are myriad future interactions possible between the natural environment and societies that rely on the environment and its services. At the same time there is a pressing urgency to use available knowledge for developing sustainable policy options (e.g. Fischer et al., 2018; Watt et al., 2018). Scenarios and models draw on assumptions about potential futures and allow for an exploration of the interactions arising from combining various streams of knowledge, even when there are knowledge gaps. Scenarios and models can be a powerful tool for accounting for scientific uncertainties and for policy and decision support (Carpenter et al., 2006; Kok et al., 2015; O'Neill et al., 2015). Scenario-based approaches provide decision makers with accessible storylines of potential future changes that act as valuable heuristic to explore and identify the implications of assumptions about future societies in different social, political, and environmental contexts (IPBES, 2016a; Kok et al., 2015; O'Neill et al., 2014; Rounsevell and Metzger, 2010).

The parameterisation of such storylines as input variables for computational models allows the development of quantified sectoral indicators and mapped outputs. Integrated assessment modelling (Dunford et al., 2015; Obersteiner et al., 2016; Priess et al. 2018; Stehfest et al., 2014) explicitly considers interactions between different land uses under different climatic and socio-economic scenarios. It also provides a mechanism for examining the synergies and trade-offs between land uses and implications for ecosystem services in a more holistic fashion. As such, integrated assessment modelling can be used as a test bed for assessing the effects of alternative land use policy options in different scenarios (Dunford et al., 2015; Harrison et al., 2013; IPBES, 2016; Spangenberg, 2007, Kok et al 2018). However, the potential of this kind of policy-screening analysis using scenarios and models is not yet fully explored (IPBES, 2016). Exceptions include – at the global level – the Global Biodiversity Outlooks (e.g., Secretariat of the Convention on Biological Diversity, 2014), the OECD's Environmental Outlook (OECD, 2012), and Rethinking Global Biodiversity Strategies (Ten Brink et al., 2010). However, to understand if and how future land use change, and resulting ecosystem services change can actually and effectively be addressed by concrete policy option(s), it is important to understand the governance processes and underlying structures (Wurzel et al., 2013; Primmer et al., 2015). More specifically, the usefulness of scenario and modelling approaches can be further improved by assessing the institutional compatibility of the policy options under review (IPBES, 2018, 2016b; Perrings et al., 2011; Theesfeld et al., 2010).

Analysing institutional contexts and assessing institutional fit is a vital part of policy analyses (e.g., Mandryk et al., 2015; Turpin et al., 2017). These analyses help to understand, for example, incentive structures in different decision-making contexts or informal institutions as important parts of the institutional environment which is usually very place-and scale-specific. Thus, they provide policy-makers with insights concerning potential institutional incompatibilities (Amblard and Mann, 2011; Theesfeld et al., 2010). Recommendations for overcoming such institutional incompatibilities and, thus, for making concrete policy options effective, include necessary changes to existing formal institutions, such as legal provisions or (other forms of) policies, but also implementing accompanying policies that establish and/or improve reliable monitoring systems and advisory services. However, whether these changes in turn facilitate achieving policy goals often remains underexplored in policy analyses. Scenarios are useful in this context, as they provide opportunities to explore how policy options play out in different institutional contexts (Brown et al., 2015). Combined with scenarios, models allow the examination of the impacts of these policy options, i.e. whether options achieve their goals in the longer term (Brown et al., 2015, Fischer et al., 2018).

The aim of this paper is to explore the added value of combining institution-oriented policy analyses with scenario-modelling approaches for improved assessments of land use policy options in terms of their institutional compatibility and long-term impacts.

The remainder of the paper is structured as follows. In Section 2, we outline the process of combining scenario analysis and modelling with policy analysis. In Section 3, we present the results of this process by describing the land use changes under the different scenarios and associated policy options. We also discuss the robustness of certain types of policy options developed for one particular scenario as they are applied within the three other scenarios developed throughout the process. We then reflect, in Section 4, on methodological limitations, but also on other lessons learned for both academic audiences and for policy makers, and finally draw conclusions.

2. Methods

In this section, we introduce the scenario-modelling approaches and describe how we combined the outputs of these with an expert-based policy analysis.

<u>Scenario-modelling approaches</u>

To explore the added value of combining policy analyses with scenario-modelling approaches for improved assessments of land use policy options we have chosen the most recently available EU level environmental scenarios (Priess et al., 2017). These scenarios provide storylines with information on diverse institutional settings as test beds to assess the institutional compatibility of different policy options. Four scenario storylines were developed to reflect different positions on two axes related to two institutional uncertainties: 1) Is future policy making predominantly sectoral or cross-sectoral? and 2) Is the governance structure (i.e. decision making) concentrated at the EU level or dispersed at national or lower levels? The four scenarios created were: UnitedWeStand (UnitedWeStand: sectoral; concentrated), WealthBeing (WealthBeing: sectoral; dispersed), EcoCentre (EcoCentre: cross-sectoral; concentrated), and RuralRevival (RuralRevival: cross-sectoral; dispersed) (Box 1).

Box1: Summary of storylines of the scenarios providing details on institutional settings.

UnitedWeStand: General policy tendencies: European policy approaches, sectoral policies; "European Dream" through strong social change and EU policies towards equity and justice; Strong EU economy and competition for labour force; Substitution of ES by technological solutions (flood protection; fracking, GMOs, intensification, etc.) but nevertheless long-term decrease of ES supply due to high demands by multiple users; Strong exploitation of natural and geological resources (e.g., mining); Due to increasing numbers of (skilled) immigrants and strong social and family-friendly policies, slight increase in birth rates; Ecosystems with high cultural value kept in museum-like state.

WealthBeing: General policy tendencies: Sectoral policies and large differences between members states (MS); Lowering social and environmental standards which results in further degradation of ecosystems and agricultural and aquatic systems in the long-term; Deregulation of markets and Nationalism; Strong individualism and consumerism; Preference for urban lifestyle, rural areas neglected; High tourism and recreation demand, especially in artificial environments; Unsustainable use of all ES, but focus on provisioning services (especially meat production and renewables) with strong intensification; Potential conflicts with nature conservation; Strong focus on economic growth by agricultural intensification; High technical efficiency and strong alliance between agrarian and industrial lobbies; Shrinkage of European population is ongoing.

EcoCentre: General policy tendencies: European policy approaches; Cross-sectoral integration; From co-design of EU policies to decentralized decision making; Strong environmental EU policies with complementary approaches: ES and Rewilding?; European wide environmental education campaigns; Voluntary reduction of consumption and movements towards sustainable lifestyles; Climate and biodiversity friendly; Technology development towards efficiency and recycling; Focus: ES concept to promote sustainable management of natural resources; Agricultural production often converted to organic or sustainable farming.

RuralRevival: General policy tendencies: little to no EU policies and little coordination in Europe, but national cross-sectoral policy initiatives; Large differences between MS; Intrinsic motivation for nature conservation; Low consumption lifestyle and strong social pressure for sustainability; Green, idealistic citizen movement; Less wealth-oriented; Strong decrease of population; Little to no urban sprawl and land sealing; Revival of rural life; Growing networks of exchange for old crop varieties, vegetables, fruits, and old livestock races; Policies and institutions move towards more cooperation; "Back to nature".

Source: Priess et al. (2017)

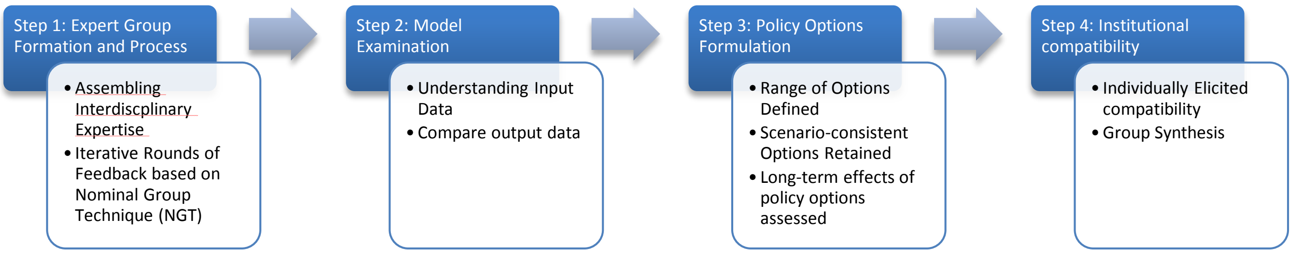
To explore the long-term impacts of different policy options in different institutional settings two integrated assessment models (IAM) were used: 1) the regional IAM CLIMSAVE Integrated Assessment Platform (IAP) (Harrison et al., 2015) and 2) the GLOBIO model operating within the global IAM Framework IMAGE 3.0 (Stehfest et al., 2014). The models were employed to assess the land use impact of the four scenarios. Both models are capable of exploring combined socio-economic and climatic changes and their consequences for land use, biodiversity, and ES (Alkemade et al., 2009; Dunford et al., 2015; Schulp et al., 2012). IMAGE-GLOBIO, a global modelling framework, provides a global overview with detail for large world regions including global connections between world regions, while CLIMSAVE is customized for the European context and needs to make assumptions about the interactions with the rest of the world, such as import and exports of commodities. During model parameterisation, input settings for the two models were customized as closely as possible to the assumptions about the change of driving forces (e.g., population development, GDP, dietary preferences, climate) identified by the scenario developers (see Hauck et al., 2015 and Priess et al., 2017). Due to the different spatial scope of the two models, it was possible to customize CLIMSAVE closer to these assumptions, whereas IMAGE-GLOBIO had a limited ability to customize input settings beyond the overarching global scenarios (i.e. IPCC Shared Socio-Economic Pathways scenarios (SSPs) (O'Neill et al., 2015). The quantified key model drivers for Europe are presented in Table 1.

Although the two models differ in their modelling approaches and spatial scope, comparing the results of both models allows the identification of common trends, as well as taking uncertainties into account arising from different conceptualizations and simplifications of the real world.

2.2 Expert-based policy analysis

We developed a stepwise process to utilize the scenario-modelling approaches for an analysis of land use policy options concerning their institutional compatibility and long-term impacts (Figure 1). The analytical approach was inspired by the framework of Brown et al. (2015) for identifying robust policy options to manage environmental change. Robustness is defined as achieving a desired outcome when also confronted with institutional settings of different scenarios. To further define these settings, we use a formalized ex–ante methodology for policy analysis, the Procedure for Institutional Compatibility Assessment' (PICA) (Theesfeld et al., 2010). PICA helps to identify potential institutional incompatibilities between policy options and the concrete institutional contexts in which a policy option is to be implemented.

Figure 1: Stepwise process to use the scenario-modelling approaches for an analysis of land use policy options in terms of their institutional compatibility and long-term impacts



Step 1: Expert Group Formation and Process

For the policy analysis, we chose an expert-based approach (Krueger et al., 2012). The expert group comprised of researchers involved in EU policy analysis, the scenario development process, and the two modelling approaches. The expert group, which is similar in makeup to the author group of this paper, consisted of researchers from different backgrounds ranging from social scientists, including political science, sociology, human geography, and economics, to natural scientists involved in different ecological fields related to climate change, land use change, biodiversity, and ecosystem services.

The Nominal Group Technique (NGT) was chosen to organize the discussion process (e.g., Clemen and Winkler, 1999). Experts are asked to individually reflect and generate ideas based on predetermined questions asked by a facilitator. Subsequently, participants are asked to collectively prioritize the ideas and suggestions issued by the group members (Harvey and Holmes, 2012). The process allowed us to combine individual and collective reflection, to explore novel concepts, and eventually generate a list of prioritized actions and/or recommendations (Coker et al., 2013; Rankin et al., 2016, for further benefits of the approach see, for example, Huge and Mukherjee, 2017 and Krueger et al., 2012). There is some criticism of NGT. NGT is a version of the Delphi method where the feedback step takes place during a face-to-face meeting of experts instead of filling in anonymized questionnaires. For such group settings, Ayyub (2001) highlights the following as potential limitations: socially reinforced conformity within the group, dominance of strong-minded or strident individuals, group motive of quickly reaching agreement and group-reinforced bias due to common background of group members.

To mitigate these potential limitations, the expert elicitation was guided by a facilitator to ensure that individual personalities and other characteristics did not exert a disproportional effect on outcomes. Multiple iterations of individual expert elicitation followed by group discussion and synthesis is a valuable technique to avoid confrontation while allowing for a wider range of perspectives to be aired (Dalkey and Helmer, 1963). Multiple rounds of iterative feedback also allow for the attenuation of institutional and psychological biases (e.g., Hannagan and Larimer, 2010). If no consensus could be achieved, policy options were dismissed.

We acknowledge that the extension of this group, to include more researchers and particularly non-scientific expertise, would have enriched our findings (Krueger et al., 2012). However, this work was done in a particular project context (http://www.openness-project.eu/) with limited resources assigned to the cross-disciplinary activities described here. Over a period of two years, a series of personal and online meetings were organized to develop and conduct the analysis presented in this paper using NGT.

Step 2: Model examination

Considerable time was invested to first individually and then jointly examine the output of the two modelling approaches, i.e. the model output-based data visualizations showing the relative land use changes between 2010 and 2050 for cropland, forest, and grassland under the four scenarios. The aim of this step was to ensure that all experts understood how the modelling approaches work, for example, in terms of input from the scenarios and their quantified drivers and model output (for a more detailed description of inputs and their incorporation into the modelling approaches see Hauck et al., 2017). Contrasting results from the CLIMSAVE and IMAGE-GLOBIO modelling exercises were used to highlight and explore the differences in model input data, as well as model-specific mechanisms and assumptions leading to different outcomes. In particular, a proper understanding of the model outcomes, i.e. the land use changes, was the basis for developing and exploring land use policy options and their potential long-term consequences.

Step 3: Expert-based development of policy options within different scenarios

Based on the individual, critical examination of the modelling results, members of the expert group provided policy options within each scenario that a) were consistent with the scenario and b) could have led to, i.e. triggered or at least fostered, land use changes provided by the IAMs. The identification of policy options was based on expert opinion established during many years of land use policy analysis and was further informed by an extensive review of regulatory frameworks (Bouwma et al., 2017; Schleyer et al., 2015) and other literature.

In a second step, these policy options where discussed by the group, jointly considering the two criteria mentioned above. Policy options were dismissed when, after deliberate discussion, an inconsistency with the scenario became evident. Further, policy options were omitted when there was an established doubt regarding the potential for a policy option to cause a respective land use change.

Following these two criteria, a table was developed (see Table 1) where, according to each scenario, policy options were summarized that were consistent with both the scenarios storylines and quantified drivers as well as the insights from the modelled land use change from the IAMs. Land use change across the two models was then summarized in terms of change in cropland, forest, and grassland in the particular scenario.

Step 4: Expert-based assessment of the institutional compatibility of policy options across different scenarios

In this last step, we used the list of plausible policy options selected or developed for one particular scenario and explored whether these policy options would be robust, i.e. achieve their desired outcome when confronted with institutional settings of different scenarios. Each member of the expert group did this exercise individually, i.e. scored robustness as low, medium, or high.

Inspired by PICA (Theesfeld et al., 2010), the institutional dimensions inherent in each respective scenario storyline to be considered were: 1) formal and informal rules, which can shape whether actors actually change their behaviour, based on a particular policy option (e.g.; incentive vs. subsidy); 2) governance structures, necessary to make new policy options effective (e.g. sectoral vs. cross-sectoral policy making; EU vs. national-level decision making); and 3) institutional incompatibilities concerning targeted actors' values and beliefs which may or may not be in line with policy objectives, or actors may not have the necessary resources, competencies, and knowledge to comply with the rules.

Results of the individual assessments were discussed, and joint conclusions were developed.

3. Results

In this section, we provide plausible narratives linking the modelled land use changes in the scenarios to the policy options (Table 1). It should be noted that a particular policy option is highly unlikely to be fully responsible for a concrete land use change; instead often complex combinations of drivers are involved in causing land use changes (e.g., IPBES, 2016b) . Rather, we assume that the policy options might have triggered or fostered changes. In addition, it is unlikely that respective policy options would be designed exactly and in all details in the same way in all scenarios. Thus, we refer to types of policy options allowing for some scenario-dependent variations in detail, such as targeted actors or regions, premium levels or production ceilings/restrictions.

	Key components of scenario storyline	Quantified drivers as key model inputs	Policy options	Modelled Land Use Change
WealthBeing **Dispersed decision making;** **sectoral policy options**	Large political and economic differences between MS & globally. national legislation strengthened; deregulation of markets.	Population and GDP: ▲ Food imports to EU: ▼ Meat consumption: ▲ Technology use: ▲ Behaviour change (water): ▼ Agricultural yields (intensity): ▲ Bioenergy crops: △ Arable land set aside: 0	Liberal trade policy ⇧ **Subsidies: woody biomass** ◆ Subsidies: agri-tech ⇧ Subsidies: energy crops ⇩ ES framework policy ◆ Rural extensification policies ◆	Global IAM (IMAGE-GLOBIO) **Grass** △**Forest** △Crop ▼ Regional IAM (ClimSAVE) Grass ▼**Forest**▲Crop ▽
UnitedWeStand **Centralised decision making;** **sectoral policy options**	Joint EU policy approaches, sectoral policies; economic, EU and the world are developing at a comparable, moderate pace.	Population and GDP: △ / ▲ Food imports to EU: ▲ Meat consumption: △ Technology use: ▲ Behaviour change (water): ▼ Agricultural yields (intensity): ▲ Bioenergy crops: 0 Arable land set aside: △	**Liberal trade policy** ◆ **Subsidies: woody biomass** ◆ **Subsidies: agri-tech** ◆ Subsidies: energy crops ⇩ ES framework policy ◆ Rural extensification policies ◆	Global IAM (IMAGE-GLOBIO) **Grass** △**Forest** ▲Crop ▼ Regional IAM (ClimSAVE) Grass ▼**Forest** ▲Crop ▼
EcoCentre **Centralised decision making;**	Cross-sectoral EU policy integration; EU leads mainstreaming of ES and	Population and GDP: ▽ / 0 Food imports to EU: ▽ Meat consumption: ▼	Liberal trade policy ⇧ **Subsidies: woody biomass** ◆ Subsidies: agri-tech ⇧	Global IAM (IMAGE-GLOBIO) **Grass** △**Forest** △Crop ▼

cross-sectoral policy options.	changes towards eco-friendly lifestyle, other countries follow.	Technology use: ▲ (water) ▽ (agri.) Behaviour change (water): ▲ Agricultural yields (intensity): 0 Bioenergy crops: 0 Arable land set aside: ▲	**Subsidies:** energy crops ◆↑ **ES framework policy** ◆↑ Rural extensification policies ◇↑	Regional IAM (ClimSAVE) Grass ▽ Forest ▽**Crop** ▲
RuralRevival **Dispersed decision making; cross-sectoral policy options.**	Large differences between member states; cross-sectoral integration; economically EU falls behind the rest of the world.	Population and GDP: ▼ Food imports to EU: ▼ Meat consumption:▼̲ Technology use: ▼ Behaviour change (water): ▲ Agricultural yields (intensity): ▼ Bioenergy crops: 0 Arable land setaside: ▲	Liberal trade policy ◆↓ **Subsidies**: woody biomass ◇↑ Subsidies: agri-tech ◆↓ **Subsidies:** energy crops ◆↑ ES framework policy ◇↑ **Rural extensification policies** ◆↑	Global IAM (IMAGE-GLOBIO) **Grass** △**Forest** △Crop ▼ Regional IAM (ClimSAVE) **Grass** △Forest ▼**Crop** ▲̲
Key to symbols For quantified drivers and land use change: ▽ Decrease 0-10%; ▼ Decrease 10-20%; ▼̲ Decrease > 20%; 0 No Change; △Increase 0-10%; ▲ Increase 10-20%; ▲̲Increase > 20%; For policy options: ◆↑ **Highly Prioritised;** ◇↑ Prioritised; ◇↓ Not prioritised; ◆↓ Deprioritised;				

Table 1 Overview of policy options consistency with scenarios storylines, quantified drivers, and the insights from the modelled land use change from the IAMs.

3.1 Subsidies for technology-driven intensification of agricultural production

This type of policy option was developed in UnitedWeStand mainly to satisfy increasing demands for agricultural production, to reduce land surface needed for agriculture to have more land available for woody biomass production, and to reduce water used for agricultural production purposes by improving or developing appropriate (production) technologies. According to the experts' assessments, this policy type was likely to be selected and effective in WealthBeing, too, although perhaps with a lesser focus on water savings. Furthermore, while this policy option might take the form of direct subsidies to farmers and other land users in UnitedWeStand, in WealthBeing the policy may rather work through incentives to establish Public-Private-Partnerships or financing respective research. The experts expected this type of policy option to play only a modest role in the EcoCentre scenario, with a focus instead on the water-saving effects of new technologies to allow for a more sustainable (less intensive/organic) farming. In RuralRevival, however, this policy option is not likely to be of any importance due to its dominant perspective of 'back-to-nature' and, by and large, 'technological-extensification' approach.

(Hodge et al., 2015)(Ramcilovic-Suominen and Pülzl, 2016)(Winkel and Sotirov, 2016)(de LT Oliveira et al., 2017)

3.2 Liberal trade policy

This originally UnitedWeStand-featured policy option pursues, amongst others, the objectives of increasing overall economic prosperity by placing few restrictions on exports and imports – focusing, however, on trade activities between EU Members States, while establishing some measures to protect the EU market from negative impacts. Furthermore, it aims at satisfying increased demand for agricultural products within the EU, despite an increase in the proportion of agricultural land converted into areas for the production of woody biomass. This policy option also features prominently in WealthBeing (step 4) as a means to foster (national) economic prosperity. Yet the concrete design of this policy option, and, thus, the degree of 'liberalism' in trade is likely to vary strongly among European countries. Liberal trade policies are assumed also to play some role in the EcoCentre, where trade policies are not really at the centre of activities, yet international trade – at least within the EU – in general is encouraged. Again, this policy option is not relevant in RuralRevival, with its focus on the promotion of local and regional level activities.

3.3. Subsidies for woody biomass production

This policy option has its origin in both UnitedWeStand and WealthBeing scenarios, in both cases with the objective of meeting an increased energy demand triggered by economic prosperity and high consumption life-styles in a profitable way. However, whilst in UnitedWeStand this policy option is embedded in – or at least accompanied by – a strong EU Common Forestry Policy, in WealthBeing there are rather diverse national policies in place. Respective payments are also expected by the experts to play a significant role as part of the Integrated Ecosystem Service Framework policy (see 3.5) in EcoCentre fostering, amongst others, multifunctional forestry (EU 2013). Perhaps at a somewhat smaller scale, regionally-specific types of these direct payments are likely to be observed also in RuralRevival.

3.4. Subsidies for annual energy crops

Due to high demand for alternative sources of energy, subsidies for annual energy crops to a certain degree supplement subsidies for woody energy crops in RuralRevival (step 3) as well as in EcoCentre aiming at climate-protection. However, in the opinion of the experts, in EcoCentre, subsidies for non-woody energy crops will be (only) one component within the Integrated Ecosystem Services Framework policy, and, thus, linked to strong requirements to ensure a sustainable, non-intensive form of production. Further, in RuralRevival the level of these subsidies is likely to be lower and more regionally diverse compared to EcoCentre. In WealthBeing and UnitedWeStand, in turn, energy-crops and respective policy options almost exclusively take the form of woody-biomass payments, thus, this policy option will not feature prominently here.

3.5. Integrated Ecosystem Services Framework policy: Payments for providing regulating services and promoting multifunctional forestry

The Ecosystem Services Framework policy option has its origin in the scenario EcoCentre and aims at a (more) balanced provision of all categories of ES, in particular taking regulating services into account. The experts assume that similar, yet nationally and regionally-focused policy options for an integrated provision of ES can also be expected in RuralRevival. In turn, there will be no Ecosystem Services Framework-policies in UnitedWeStand and WealthBeing: WealthBeing does not feature EU-level-based integrated policy options, nor does it focus on ES beyond selected and intensively produced provisioning services, or on multifunctional forestry; the latter also holds for UnitedWeStand which also employs technological solutions to account for an unbalanced or unsustainable provision of ES.

3.6. Rural development policy options supporting agricultural extensification of cropland

Rural development in its non-intensive way of producing agricultural products and the decentralized policy approach makes it an important policy in RuralRevival with the objective of fostering traditional, environmentally-friendly ways of farming. In the EcoCentre, such rural development policy option will, again, be one component of the Ecosystem Services Framework-policy. However, the experts assume that the total area covered by this extensification of cropland farming policy might be rather small due to an increasing demand for bioenergy crops, afforestation, and rewilding. Finally, due to the strict focus of agricultural intensification and/or technology-based solutions in UnitedWeStand and WealthBeing, the experts do not predict that this policy will be of any relevance in UnitedWeStand and WealthBeing.

4. Discussion and conclusions

Our synthesis approach reveals a number of lessons learned that are of interest for policy-makers, and are outlined in Section 4.1. In Section 4.2, we discuss the shortcomings of our approach and the methodological lessons learned for future work on integrating policy analysis with scenarios and modelling approaches. We conclude by reflecting on our personal interdisciplinary learning.

4.1 Lessons learned for policy-makers

Policy-makers design or select specific policy options to encourage or prevent certain activities or decisions of targeted actors which are then expected to help reach certain societal objectives or goals. Often they need to make their decisions with varying degrees of uncertainty, i.e. with a lack of knowledge about the potential consequences of their decisions. Depending on the specific details of the policy design, as well as the overall institutional context or framework conditions, some policy options are more likely to reach the intended objectives than others, and to be selected or designed in the first place. These decisions can be informed by analyses, for example, using scenarios, modelling, and expert-based institutional compatibility assessments to provide a broader perspective on what could happen and how viable the policy options are under different assumptions about the future and in different institutional contexts.

In the following, we discuss which policy options we consider to be robust across different scenarios and which policy options work only under certain institutional and other conditions. Before we discuss particular findings, it is important to point out that our findings should not be considered as recommendations for future policy making. As the scenarios described in this paper present alternative visions of the future, they should be considered as “food for thought”(Loorbach, 2010). In other words, IAM findings cannot be easily translated into concrete advice such as “if you implement this policy, change in grassland/arable land/forest will be X%”. Prominent uncertainties of the scenario and modelling approaches, such as the scientific (i.e., relating to our knowledge of the subject and available models and data) and stochastic (i.e., resulting from the inherent unpredictability of complex systems) preclude direct policy advice at these early stages in the policy cycle (IPBES, 2016a). Drivers characterised by a high degree of uncertainty, such as technological and socio-cultural indirect drivers have the potential to quickly and drastically alter direct driver trajectories (Perez, 2004). Additionally, one should take into account that decisions are taken for a variety reasons, and are rarely based only on the knowledge that goes into the decision-making process (Young et al., 2014; Waylen & Young, 2014).

Uncertainties are increased by the long time horizon of our approach to 2050. As a methodological approach, exploratory scenarios allow for a mapping of scientific and stochastic uncertainties in drivers of change (IPBES, 2016a; Regan et al., 2005). By examining a range of future scenarios (frequently with scenario-specific variants) rather than a single specific future, scientists are better able to account for a variety of indirect and direct scenario driver trajectories (Peterson et al., 2003). Scenarios and modelling are, therefore, tools to help account for various forms of uncertainty.

The issues with uncertainties become particularly visible when looking at the different modelling results for grassland. CLIMSAVE chose to allocate land which is not needed for agricultural purposes to forestry above the less productive grassland, whereas IMAGE-GLOBIO differentiated in terms of whether the land would be allocated to forestry or grassland based on model-specific land use dynamics (Doelman et al., 2018). The disagreement over what constitutes pasture and forest is also widely acknowledged in the literature (Alexander et al., 2017; Kipling et al., 2016; Sierra et al., 2015). Due to differences in the underlying assumptions of the two modelling approaches (e.g., land use allocation rules, land use definition), outcomes in terms of changes in grassland coverage differ significantly, and policy options could not be designed that would make sense in both models. These and other kinds of uncertainties inherent in modelling approaches need to be taken into account when policy makers take results into consideration (see also, IPBES 2016b). However, while there are uncertainties concerning grassland, across both models it became clear that pressure on grassland is significant in all scenarios, and if conservation of grassland is on the agenda, strong protection policies should be designed.

Apart from the more general lessons, in the following we discuss the policy options in more detail:

- *Subsidies for technology-driven intensification of agricultural production*: This policy option made sense across all scenarios, except RuralRevival. There are certainly different intentions for this policy, and different technologies are supported within the respective scenarios accordingly. However, in a number of scenarios these kinds of subsidies would contribute to decreasing demand for cropland, but may also have side effects on other policy objectives. While we do not take a position in the land-sparing versus land-sharing debate (e.g., Phalan et al., 2011), within the current modelling exercise and the European context, we find that land is spared by increasing yields on existent cropland rather than expansion of agricultural lands. If not managed sustainably, however, nutrient emissions from agriculture can have significant negative effects on biodiversity and ES, particularly within freshwater and coastal ecosystems (Jenny et al., 2016; Pretty et al., 2003; Smith et al., 1999). From an institutional economics perspective, however, the cost-effectiveness of this policy option is likely to be different across the three scenarios it is considered likely to be implemented in. For example, policy options harmonised across sectors (like in EcoCentre) will provide more consistent incentives to individual land users than a sectoral approach with potentially conflicting priorities. On the other hand, regionalised policy designs may be more effective with respect to ecological effectiveness, yet come along with higher costs of governing (Lehmann et al., 2009).
- We found an even greater robustness for *subsidies to promote biomass production*, which generally made sense in all scenarios, albeit with major differences in the type of biomass promoted. This policy could result in a significant increase in forest areas as indicated in all scenarios from the global IAM, but may also lead to large tracts of natural forests coming under various degrees of management, with negative implications for biodiversity and ES. Furthermore, depending on their magnitude and implementation, increased subsidies for biomass production may lead to increased land competition, as well as indirectly resulting in the expansion of agricultural land at a cost to natural land and pastures through indirect land use change (Havlík et al., 2011; Lambin and Meyfroidt, 2011). Thus, the actual effect of those subsidies does not only depend on their concrete design, but also on the institutional context they are implemented in. In particular, the existence, or not, of detrimental policies or legal frameworks promoted by other sectors may reduce the effectiveness of the subsidies. Here, settings/scenarios featuring cross-sectoral coordination like EcoCentre and UnitedWeStand are likely to show higher degrees of cost-effectiveness for these subsidies.
- *Liberal trade policy* is originally UnitedWeStand-based and features prominently in WealthBeing, but may also play a role in EcoCentre. With its focus on fostering production and deregulation of markets, it may vary strongly among European countries. This makes it difficult to assess the overall impact on land use, but pressure on land might increase, albeit mitigated via intensification. Thus, without regulations balancing potential negative impact on biodiversity and ES, 'negative' effects could prevail. Due to European reliance on food imports from overseas, a more competitive and deregulated marketplace may be mitigated by ongoing increases in production and efficiency from exporting countries. Spatial decoupling of agricultural production and consumption in Europe makes it difficult to draw implications given Europe's rolein global markets (Fader et al., 2013; Meyfroidt et al., 2013).
- *Integrated Ecosystem Services Framework-policy* only made sense within the context of one particular type of scenario, the EcoCentre. That means: it can operate only under specific circumstances (e.g., European policy approach, cross-sectoral integration, ES-driven policy making)

and needs particular efforts. It could, however, result in significant benefits, not so much in the total area of land use changed, but for the management of land use. An Ecosystem Services Framework policy could be an important tool to ensure that land use is developed towards the provision of multiple ES looking not only at productivity, but also at the provision of regulating and cultural ES. However, ex-ante institutional analysis may reveal that Members States – or regional administrations – differ in their ability to implement such a rather complex policy framework and to ensure a fair and decentralized decision-making process leading to (cost-)effective regionalised programs of policies. It may also indicate lacking resources and capacities on part of the Member States and regional administrations to effectively monitor and sanction these policies on the ground. Indeed, Ecosystem Services Framework policy options have been reviewed and proposed in the literature (Matzdorf and Meyer, 2014; Rodriguez-Ortega et al., 2014), with small scale application at the local level (Poppy et al., 2014).

- Another policy with low general applicability is *rural development aiming at agricultural cropland expansion* featured mainly in RuralRevival, and to a much lesser extent in EcoCentre. The reason for low applicability is similar to the reason why other policy options also have a rather low fit for RuralRevival: the institutional context, in particular the governance modes and, more importantly, the 'scenario philosophy' differ substantially from the other scenarios. In the RuralRevival scenario, a large-scale, bottom-up transformation is assumed, driven by a societal desire to live in harmony with nature. Changes are driven by voluntary modifications in behaviour, and policy options in general are merely supporting. Top-down governance modes, independent of what they promote, are considered to be inappropriate here. Rather, flexibility, participation, and local and regional collaboration are important. Thus, informal institutions do seem to play a much larger role here compared to the other scenarios. Within CLIMSAVE, questions are raised about the challenges of being self-sufficient under the climatic scenarios and the potential problems that result from turning our backs on technological progress. The RuralRevival distribution shows that there is considerable potential in the (European) North to maximize opportunities with regard to crops – and significant challenges in the South where this will no longer be possible.

When reviewing our findings, it is important to recall that the policy options we suggested are rather aggregated, i.e. they are not envisaged as concrete instruments or measures, but rather policy types.

4.2 Lessons learned at the interface of science and policy

In this section, we reflect on the methodological lessons we learned for future work on integrating policy analysis with scenarios and modelling approaches and on personal interdisciplinary learning.

For the policy analysts who took part in this synthesis exercise it was very helpful to obtain a better understanding of the concrete modelling approaches used. For both the policy analysts and the modellers, the discussions made both the underlying model assumptions and algorithms used to 'project' land use changes more clear and transparent. In particular, capturing the – partly – different assumptions for projecting changes in grassland, and thus the substantial variances in results, proved to be important for finding policy options that might have triggered these changes. A better understanding of the modelling approaches also showed the benefits of using them for policy analyses, as it required policy analysts to go beyond more traditional ex-post policy analyses as conducted, for example, by Schleyer et al. (2015) and

Bouwma et al. (2017), and to think about ex-ante future policy options. Furthermore, adopting an institutional perspective to the overall policy analysis was considered to be very helpful in highlighting crucial dimensions affecting, for example, the cost-effectiveness of policy options. Modellers considered the exercise helpful for improving future model development, linking it better to policy options right from the beginning (e.g., how to feed ES policy options into the modelling as a driver, rather than as a response or something we think about after the modelling is done).

The scenario and modelling approaches provided a good boundary object-type (Leigh Star, 2010) to facilitate interdisciplinary discussion for providing lessons learned perhaps interesting for policy makers. According to Star (2010, p. 602) "[b]oundary objects are a sort of arrangement that allow different groups to work together without consensus". More specifically, boundary objects can be understood as collaborative products that are both adaptable to different viewpoints and robust enough to maintain identity across them (Star and Griesemer, 1989; Clark et al., 2011). Examples of boundary objects are reports, models, forecasts, scenarios, newsletters, and even conferences or workshops (e.g., Cash and Moser 2000; Cash et al., 2003; McNie, 2006; Clark et al., 2011). They are co-produced by all participants and, by virtue of this, facilitate communication, cooperation, debate, evaluation, review and accountability (Star and Griesemer, 1989). In our case, the scenarios and modelling served as a basis to gain a joint understanding from which we could single out the general types of policy options among the broad mechanisms that are applied in the governance of biodiversity and ES (Primmer et al., 2015). Discussing this kind of general policy mechanism ideas, Jäger et al. (2014) refer to policy archetypes and define them even in broader governance-mode-like terms, which they consider to be robust under several different futures and, thus, able to 'work' even if uncertainties are high.

We also found certain limitations. Different modes of governance need to be modelled in different ways. The integrated models used in this paper employ a particular logic with regard to how land is allocated to meet demand for commodities in ways that assume optimisation across Europe (CLIMSAVE) and the world (IMAGE-GLOBIO). When interpreting scenarios modelled in this way it is important to reflect on the extent to which this logic of allocation fits with the scenario logic. For example, in RuralRevival, where there is a strong drive towards localism, the redistribution of land use to meet European food demand could take place – or there might be some countries that 'win', whilst others 'lose'. It would be possible to model decisions at different spatial resolutions, and there are types of models – such as agent-based models – that are better designed to model local learning, sharing, and competition, but these kinds of ideas are not yet embedded in the state of the art models represented by CLIMSAVE and IMAGE-GLOBIO.

Apart from a vast number of interdisciplinary lessons learned, we also gained insight into the science-policy interface. A weak EU appeared as plausible scenario from a scientific perspective, given the current political environment. However, it appeared to be unacceptable at EU level policy making. At the expense of policy relevance, we decided to maintain scientific independence and looked at policy options also in the context of a weak EU yielding environmentally beneficial opportunities for regional decision making.

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