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ORIGINAL ARTICLE

# Identifying pathways to visions of future land use in Europe

**Pieter J. Verkerk[1] · Marcus Lindner[1] · Marta Pérez-Soba[2] · James S. Paterson[3] · John Helming[4] · Peter H. Verburg[5] · Tobias Kuemmerle[6,10] · Hermann Lotze-Campen[7,11] · Alexander Moiseyev[1] · Daniel Müller[8] · Alexander Popp[7] · Catharina J. E. Schulp[5] · Julia Stürck[5] · Andrzej Tabeau[4] · Bernhard Wolfslehner[9] · Emma H. van der Zanden[5]**

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**Abstract** Plausible scenarios of future land use derived from model projections may differ substantially from what is actually desired by society, and identifying such mismatches is important for identifying policies to resolve them. This paper presents an approach to link explorative projections of future land use for the European Union to normative visions of desired land-use futures. We used the results of 24 scenario projections obtained from seven linked simulation models to explore uncertainty in future land-use developments. Land-use projections were linked to statements made by stakeholders for three normative visions of desired, future land use. The visions differed in the scale of multifunctionality of land use: at European (*Best Land in Europe*), regional (*Regional Connected*) or local (*Local Multifunctional*) level. To identify pathways to these visions, we analysed in which cases projected land-use changes matched with the land-use changes desired in the visions. We identified five pathways to the vision *Regional Connected*, two pathways to the vision *Best Land in Europe*, but no pathway to the vision *Local Multifunctional*. Our results suggest that policies have the ability to

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✉ Pieter J. Verkerk
hans.verkerk@efi.int

Marcus Lindner
marus.lindner@efi.int

Marta Pérez-Soba
marta.perezsoba@wur.nl

James S. Paterson
james.paterson@ed.ac.uk

John Helming
john.helming@wur.nl

Peter H. Verburg
peter.verburg@vu.nl

Tobias Kuemmerle
tobias.kuemmerle@geo.hu-berlin.de

Hermann Lotze-Campen
lotze-campen@pik-potsdam.de

Alexander Moiseyev
alexander.moiseyev@efi.int

Daniel Müller
mueller@iamo.de

Alexander Popp
popp@pik-potsdam.de

Catharina J. E. Schulp
nynke.schulp@vu.nl

Julia Stürck
julia.sturck@vu.nl

Andrzej Tabeau
andrzej.tabeau@wur.nl

Bernhard Wolfslehner
bernhard.wolfslehner@efi.int

Emma H. van der Zanden
emma.vander.zanden@vu.nl

1 European Forest Institute, Sustainability and Climate Change Programme, Yliopistokatu 6, 80100 Joensuu, Finland

2 Wageningen Environmental Research (Alterra), Wageningen University & Research, P.O. Box 47, 6700AA Wageningen, The Netherlands

3 Land Use Research Group, School of Geosciences, University of Edinburgh, Edinburgh, UK

change the development of land use such that it is more in line with land-use futures desired by society. We believe our approach represents an interesting avenue for foresight studies on land use, as it combines the credibility from explorative scenarios with legitimacy and saliency of normative visions.

**Keywords** Explorative scenarios · Land use · Normative visions · Pathways

## Introduction

Land use provides multiple goods and services to society and is therefore of critical importance to humans (Foley et al. 2005). However, the unsustainable use of the land significantly contributes to climate change through greenhouse gas emissions (Smith et al. 2014), to biodiversity loss (Newbold et al. 2015) and to the degradation of ecosystem services (Millennium Ecosystem Assessment 2005). Over the next decades, human population is expected to increase strongly (United Nations 2015) and the demands to produce food, feed, fibre and fuel from land are likely to continue to increase. Meeting simultaneously the future needs of a rising population while conserving natural areas, halting biodiversity loss and switching to larger shares of renewable energy, will further exacerbate the competition for land (Lambin and Meyfroidt 2011; Kraxner et al. 2013). To deal with such potential conflicts, strategies for future land use are needed (e.g. Godfray and Garnett 2014; Fares et al. 2015).

[4] Wageningen Economic Research, Wageningen University and Research, P.O. Box 29703, 2502 LS The Hague, The Netherlands

[5] Department of Earth Sciences, VU University Amsterdam, De Boelelaan 1087, 1081HV Amsterdam, The Netherlands

[6] Geography Department, Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany

[7] Potsdam Institute for Climate Impact Research, Telegrafenberg A 31, 14473 Potsdam, Germany

[8] Leibniz Institute of Agricultural Development in Transition Economies (IAMO), Theodor-Lieser-Strasse 2, 06120 Halle (Saale), Germany

[9] European Forest Institute, Central-East and South-East European Regional Office, c/o University of Natural Resources and Life Sciences, Feistmantelstr. 4, 1180 Vienna, Austria

[10] Integrative Research Institute on Transformations of Human-Environment Systems (IRI THESys), Humboldt-University Berlin, Unter den Linden 6, 10099 Berlin, Germany

[11] Humboldt-University Berlin, Unter den Linden 6, 10099 Berlin, Germany

Scenario analysis is considered an important foresight technique to support strategic decision-making while dealing with uncertainty (van der Heijden 2005; Pérez-Soba and Maas, 2015). Scenario analysis helps to characterise the future in a structured way that allows imaginative thinking (Rounsevell and Metzger 2010). Explorative scenarios are frequently used to describe the uncertainty in developments and to answer questions on what *could* happen. There is, however, another group of normative scenarios that aims to answer the question what *should* happen (Börjeson et al. 2006; Rounsevell and Metzger 2010; Vergragt and Quist 2011). This group of scenarios has a normative focus and addresses a desirable endpoint or vision on what is wanted and where one would like to be in the future. Combining these different scenario techniques has received little attention (Seppelt et al. 2013; Castella et al. 2007).

To identify pathways on how one can reach a desirable future, a number of backcasting approaches have been developed (Robinson 1982; Dreborg 1996). The starting point of this technique is a desirable future, from which the analysis goes backwards to the present in order to determine the feasibility of that future, as well as to search for decisions (e.g. policy measures) and conditions that would be required to reach the desired endpoint. Recent backcasting efforts do not only rely on simulation modelling, but often include participatory feedback by stakeholders to define the desired visions, to identify possible obstacles to reach the vision or to refine the proposed policy or management choices necessary to reach the vision (Robinson et al. 2011; Kok et al. 2011). Backcasting has been applied, for example, in studies on sustainable development (e.g. Robinson et al. 2011), water management (van Vliet and Kok 2015), waste management (van der Pluijm et al. 2010) and recently also for regional-level land-use planning (Haslauer 2015; Brunner et al. 2016). Yet, backcasting has not been used in large-scale land-use foresight studies. Presumably this is because of the methodological complexities of backcasting land-use dynamics or because stakeholders may disagree and thus not share a common vision for future land use.

Combining explorative scenarios with normative visions is an interesting approach for land system science (Castella et al. 2007; Rounsevell et al. 2012; Seppelt et al. 2013), because such an approach combines the credibility of explorative scenarios, as perceived by stakeholders, with the perceived legitimacy and saliency of normative visions (Rounsevell and Metzger 2010; Pérez-Soba and Maas 2015). Striking a balance between the credibility, saliency and legitimacy is important to effectively support decision-making (Cash et al. 2003). In this study, we tried to combine explorative scenarios with normative visions on future land use. The aim of our study was to identify pathways to the future land use desired by European stakeholders by linking their normative visions to explorative scenarios simulated with a hierarchical set of land-use models. Specifically, our objectives were (1) to develop an approach to link quantitative model projections to qualitative visions statements by stakeholders, (2) to apply the approach to the three visions of land use in Europe and (3) to discuss the approach as a decision support tool in land-use policy and planning.

## Methods and data

### Visions of future land use

Normative visions of future land use in the European Union (EU) have recently been elicited by Pérez-Soba et al. (2015) in a participatory stakeholder process. This process resulted in three distinct land-use visions for the year 2040, all having multi-functionality at their core, but differing in the spatial scale at which multi-functionality should occur, i.e. European, regional or local. *Best Land in Europe* is a vision in which optimal use of land is crucial to ensure maximum production of food and other natural products. *Regional Connected* is a vision in which societal needs are met regionally, in a coherent relationship between people and their resources. Finally, in the vision *Local Multifunctional*, a diversity of land functions co-occur in small areas, based on innovative approaches to living, working and recreation, with a high diversity in goods and services, land uses and society. A detailed description of the three visions is given by Pérez-Soba et al. (2015). We used these three visions as the desirable future for which we aimed to identify pathways.

### Land-use projections

To identify pathways to the three future land-use visions, we used simulations (Lotze-Campen et al. 2013; Verburg et al. 2013; Stürck et al. 2015), derived from seven global and regional land-use models for 27 European countries (i.e. the EU excluding Croatia). The global models REMIND and MAgPIE provided trajectories on economic growth and population growth, food and bioenergy demands, and land-use change for major world regions. These outputs were used by the models MAGNET and EFI-GTM. MAGNET is a global general equilibrium model, covering all economic sectors and projecting global changes in land use, agricultural production and consumption patterns, and regional sub-sector-specific changes in bilateral trade flows. EFI-GTM is a global forest sector model which uses changes in economic development and population as an input to derive future trends in consumption, production and trade of wood and wood products. Simulation results from these global models were used as input to the agricultural economic model CAPRI and the forest resource projection model EFISCEN. CAPRI used outputs from MAGNET to calculate region- and product-specific outputs (e.g. yields and fertilizer use). EFISCEN projected future wood supply from European forests and resource development, based on the domestic demand for roundwood, as projected by EFI-GTM. CAPRI and EFISCEN provided spatially detailed insights into the agricultural and forest land-use sectors in Europe at the regional-level. To account for all changes in land cover and to ensure consistency between the different types, the Dyna-CLUE model was included in the model chain. The Dyna-CLUE model allocates demands for land use from different sectors on a high-resolution spatial grid based on location factors, land-use history, spatial policies and competition between land uses. For references to the models, we refer to Table S1 in the Supplementary Online Material.

Lotze-Campen et al. (2013) and Verburg et al. (2013) applied this modelling framework to explore how land use would change according to four alternative global development scenarios (A1, A2, B1 and B2), as well as to assess how eleven policy options would alter two of the four global development scenarios. In total, they developed 24 scenarios (Table 1, Table S2), which we used for our analysis. Projection results were used at the level of administrative regions (Nomenclature des Unités Territoriales Statistiques—NUTS—level 2).

The process to define visions and the implementation of the modelling framework were only loosely linked by focussing on land use. The detailed development of the modelling framework and the definition of the scenarios were conducted mostly independent from, and in parallel to, the eliciting of visions. This was done to prevent that stakeholders would be constrained in formulating their visions by the ability of the models to project future land use, but comes with the trade-off that some of the visions may contain aspects, or focus on scales, that are less well represented in the models than those of other visions.

### Linking land-use projections with stakeholder visions

To structure the linkage of scenario projections with visions, we identified land-use attributes that were addressed in the visions and could be quantified by the models. To do this, we pre-defined a set of land-use attributes to characterise various aspect of land use: land cover extent (i.e. the area covered by a land cover type), land-use

**Table 1** Brief description of the scenarios

| # | Global development | Code | Scenario | Brief description of policy alternative |
|---|---|---|---|---|
| 1 | A1 | A1 | Global development | Globalised world with strong economic growth and weak intervention. The Common Agricultural Policy (CAP) of the European Union (EU) is fully abolished |
| 2 | A2 | A2 | | Fragmented world with modest economic growth and weak intervention. EU CAP remains unchanged |
| 3 | B1 | B1 | | Globalised world with modest economic growth and strong intervention. EU CAP is fully abolished |
| 4 | B2 | B2 | | Fragmented world with modest economic growth and strong intervention. EU CAP remains unchanged |
| 5 | A2 | A2NP | Nature protection | A focus on nature protection, with expansion of protected zones beyond Natura2000, a robust ecological corridor network and strengthened constraints on land cover conversions and restrictions on forest management |
| 6 | B2 | B2NP | | |
| 7 | A2 | A2NW | Nitrogen and water quality | Strong reduction in the application of nitrates from animal manure to prevent further groundwater and/or surface water pollution |
| 8 | B2 | B2NW | | |
| 9 | A2 | A2AP | Agricultural productivity | Faster achievement of higher yields, e.g. through additional investments in R&D or improvements of labour/capital productivity. The budget needed is taken from the direct farm payment budget in Pillar I of the Common Agricultural Policy (CAP) |
| 10 | B2 | B2AP | | |
| 11 | A2 | A2BE | Bio-based economy and bioenergy | Demand for biomass is strongly increasing for material and energy use. Constraints on removals of logging residues and stumps from forests are less strict |
| 12 | B2 | B2BE | | |
| 13 | A2 | A2PC | Payment for carbon sequestration | Incentives to (1) limit the conversion of grassland and Payment for Ecosystem Services (PES) scheme to protect areas that are prone to carbon emissions due to their high soil organic carbon contents and (2) to stimulate carbon sequestration in forest biomass |
| 14 | B2 | B2PC | | |
| 15 | A2 | A2PR | Payment for recreational services | Direct payments to landowners (farmers and forest owners) in exchange for managing their land to provide recreational services. The budget needed is taken from the direct farm payment budget in Pillar I of the CAP |
| 16 | B2 | B2PR | | |
| 17 | A2 | A2CR | CAP reform for rural employment | Additional agricultural employment is encouraged by extra EU subsidies. Additional rural employment may trigger production intensification and reduced pressure on land. In the agricultural sector, 20 % of the EU CAP budget shifts to labour subsidy |
| 18 | B2 | B2CR | | |
| 19 | A2 | A2ZC | Zoning for compact cities | Limitation of urban sprawl and creation and maintenance of compact urban settlements and cities |
| 20 | B2 | B2ZC | | |
| 21 | A2 | A2FP | Flood protection | European-wide adoption of climate change adaptation measures |
| 22 | B2 | B2FP | | |
| 23 | A2 | A2AE | Climate change mitigation and agricultural emission taxes | Agricultural sector has to contribute to overall emission reductions by complying with climate policy frameworks based on emission pricing through emission trading or standards |
| 24 | B2 | B2AE | | |

References to more detailed descriptions of the scenarios are given in Table S2 of the Supplementary Online Material

management (i.e. the intensity by which land is managed), land-use pattern (i.e. the spatial configuration of different land uses), land-use services (i.e. the benefits provided to society by land use), global land impacts (i.e. indirect effects of land use in Europe on land use outside Europe) and lifestyle (i.e. behaviour of people that affects land use).

In a next step, we compared a list of more than 450 model variables with statements made by stakeholders in the definition of visions and identified 20 variables that adequately captured stakeholder statements (Table S3). The selected model variables mainly covered the attributes land cover extent, land-use management and land-use patterns. We were unable to link the attributes of global land impacts and lifestyle, due to unavailability of appropriate model variables or due to absence of detailed statements by stakeholders. Stakeholders provided additional statements on land-use sectors (e.g. energy, water and transport), which could not be addressed by the modelling framework and were therefore excluded from our analysis. Similarly, many of the spatial details provided by the models were not addressed in the stakeholder visions and could not be accounted for in detail.

To avoid redundancy, we checked for correlation between model variables. We first calculated the change ratio between 2040 and the base year for each model variable (2010 for CAPRI and EFISCEN variables, 2000 for Dyna-CLUE variables) for each administrative region in our data set. In a next step, we calculated Spearman rank correlations between all model variables for the four global development scenarios separately. Correlations were generally relatively low (<0.6), except for the variables *extent of forest area* and *contribution of abandoned agricultural land to wilderness* (correlation = 0.66; Figure S1). However, these variables relate to different attributes, and therefore, collinearity among them does not to impair further analysis. All 20 model variables were, therefore, used for subsequent analyses.

## Matching desired and projected change

After selecting the model variables, we determined in which direction each of the selected variables should change over time as desired by the stakeholder for each of the three visions, and how they did change according to the scenario simulations. From the documentation of the stakeholder visions, we recorded for each model variable whether it was desired to increase (+1), remain constant (0) or decrease (−1). In addition to the desired change, weights for the model variables were defined based on statements made by stakeholders. Stakeholders only made statements for livestock in general, while the models provided three livestock variables separately. To address this, we combined the three model variables into one variable using an equal weight ($w1$) for each. Next, stakeholders expressed that a variable should change strongly. We addressed this by adding a second weight ($w2$), which received a value of 1 in case a variable was desired to change and a value of 2 in case a variable was desired to change strongly. The desired changes, and the weights, for the three visions are shown in Table 2.

Stakeholder visions indicated distinct spatial distributions for the different land uses. With regards to agricultural production, in the vision *Best Land in Europe,* the most productive areas would be used for agriculture, i.e. agricultural land-use should increase in productive and decrease in unproductive areas. Stakeholder did not, however, indicate where productive areas are located. To identify productive regions, we stratified all regions in our data set to high-, medium- and low-productivity regions. To do this, we used the agricultural productivity calculated by CAPRI as a proxy for each region in our data set. We selected the top third of all regions in terms of agricultural production assuming that these would be productive regions where the agricultural area should increase (+1), and the lowest third of regions would be the unproductive regions where the agricultural area should decrease (−1). Medium productive areas would remain stable (0). As regards forestry production, *Best Land in Europe* also implied that forest production would shift from the south of Europe to less drought-prone areas in the north. This was implemented by assigning +1 to Northern Europe, a −1 to Southern Europe and 0 to Central Europe. We grouped countries in three main geographical regions: north (i.e. Denmark, Estonia, Finland, Latvia, Lithuania and Sweden), south (i.e. Bulgaria, Cyprus, Greece, Italy, Portugal, Slovenia and Spain) and central EU (remaining EU countries). *Local Multifunctional* envisions creating local self-sufficiency by optimising the use of land and the supply of goods and services on the spot. To address the difference in scale of the vision as compared to the scale of our analysis, this was implemented in a way that all land-use forms should be present at the NUTS-2 level to a certain extent. We assumed a minimum target of 20 % for each land cover type in a region: if a certain land cover type was below 20 % of the total land area, then that land cover type should increase (+1) and if the share exceeded 20 % no change was desired (0).

To match the desired change of each variable to the model outcomes for this variable under each scenario, the projected change in each model variable between 2010 and 2040 was also reclassified into three classes. A projected increase corresponded to a value +1, no change corresponded to 0 and a projected decreased corresponded to −1. We assumed a threshold of 5 % to determine whether a variable was projected to change.

Finally, we compared the desired and projected changes for each model variable and administrative region (Figure S2). We did this by calculating the absolute difference to identify whether projected change was in full agreement (absolute difference = 0), disagreement (absolute difference = 1) or strong disagreement (absolute difference = 2) with the desired change.

## Identifying pathways

To identify pathways towards the visions, we calculated the mean level of agreement for all 24 scenarios with regards to each vision. To do this, we used the absolute difference between the reclassified, desired and projected change for each model variable (with values being 0, 1 or 2; Figure S2). We then calculated the mean value over all 20 model variables using $w1$ and $w2$ as weights, and we subtracted this mean from 1. This can be written as:

**Table 2** Desired change (*d*) and weight (*w*2) of the model variables according to the three visions

| Attribute | Variable | Abbreviation | Best land in Europe | | Regional connected | | Local multifunctional | |
|---|---|---|---|---|---|---|---|---|
| | | | *d* | *w*2 | *d* | *w*2 | *d* | *w*2 |
| Land cover extent | Extent of arable land | arab | −1/0/+1 | 1 | −1 | 1 | 0/+1 | 1 |
| | Extent of forest area | fore | 0 | 1 | +1 | 1 | 0/+1 | 2 |
| | Extent of (semi-) natural area | natu | +1 | 1 | +1 | 2 | 0/+1 | 2 |
| | Extent of urban area | urba | 0 | 1 | 0 | 1 | 0 | 1 |
| Land-use management | Crop yield | aryd | +1 | 2 | +1 | 1 | +1 | 1 |
| | Stocking density of ruminants | rumi | +1 | 2 | +1 | 1 | +1 | 1 |
| | Stocking density of pigs | pigs | +1 | 2 | +1 | 1 | +1 | 1 |
| | Stocking density of poultry | poul | +1 | 2 | +1 | 1 | +1 | 1 |
| | Roundwood removals | wood | −1/0/+1 | 1 | +1 | 1 | +1 | 2 |
| | Extracted logging residue and stumps | resi | −1/0/+1 | 2 | +1 | 1 | +1 | 1 |
| Land-use pattern | Connectivity index of semi-natural area and forest | conn | +1 | 1 | +1 | 2 | +1 | 2 |
| | Growth of peri-urban area | peri | −1 | 2 | 0 | 2 | +1 | 2 |
| | Shannon index for crop diversity | shan | +1 | 1 | +1 | 1 | +1 | 2 |
| | Contribution of abandoned agricultural land to wilderness | wild | +1 | 2 | 0 | 1 | −1 | 1 |
| Land-use services | Shadow value of agricultural land | rent | +1 | 1 | +1 | 1 | +1 | 2 |
| | Production over domestic consumption | self | +1 | 2 | +1 | 1 | +1 | 1 |
| | Global warming potential in agriculture | emis | 0 | 1 | 0 | 1 | −1 | 1 |
| | Deadwood in forest | ddwd | +1 | 2 | +1 | 2 | +1 | 2 |
| | Carbon sequestration in forest biomass | cseq | +1 | 1 | +1 | 1 | +1 | 2 |
| Global land impacts | Net trade of agri-food products | trad | +1 | 2 | 0 | 1 | 0 | 1 |

The desired changes +1, 0 and −1 indicate whether a model variable is desired to increase, not change or decrease, respectively. In case multiple desired changes are shown, a regional pattern was assumed. The weight *w*2 indicates whether a model variable was desired to *change strongly* by the stakeholders. See text for details on assumed regional patterns and *w*2

$$\text{Agreement}_{i,j,l} = 1 - \frac{\sum_{k=1}^{n} w1_k \times w2_{j,k,l} \times m\text{var}_{\text{i,k,l}}}{2 \times \sum_{k=1}^{n} w1_k \times w2_{j,k,l}}$$

where $w1$ and $w2$ denote weights (see "Matching desired and projected change" section), $m$ var denotes (reclassified) model variables, and $i$ denotes scenarios, $j$ denotes visions, $k$ denotes model variables, $l$ denotes administrative regions and $n$ denotes the number of model variables (i.e. 20). We divide by two to have all values in the range [0,1]: a value of 1 means that a scenario projection is in full agreement and a value of 0 implies full disagreement.

We assumed that for a scenario projection to be considered a pathway, a projection should agree at least to 60 % (i.e. agreement ≥0.6) with a vision for individual administrative regions and that this should apply to at least a two-third majority of the land area and population in the EU. By considering both land area and population, we prevented that small regions with high population numbers (e.g. large cities) or large regions with low population (e.g. northern Europe) would get a disproportionate weight in determining whether a scenario projection would be a pathway. Population data for all regions in our analyses were obtained for the year 2010 from EUROSTAT (2014).

To analyse how different assumptions to identify pathways would affect our results, we conducted a sensitivity analysis. We assessed the number of pathways that could be identified if level of agreement would exceed (1) 70 % between a scenario projection and a vision, (2) 60 % and apply to >50 % majority of the population and land area, (3) 60 % and apply to a two-third majority of the population (not land area), (4) 60 % and apply to a two-third majority of the land area (not population) and (5) 60 % and apply to a two-third majority of the population and land area and that the number of strong disagreements should not exceed three. We also analysed the effect of applying alternative thresholds to determine whether a model variable was projected to increase, to be stable or to decrease by applying thresholds of 1 and 10 %.

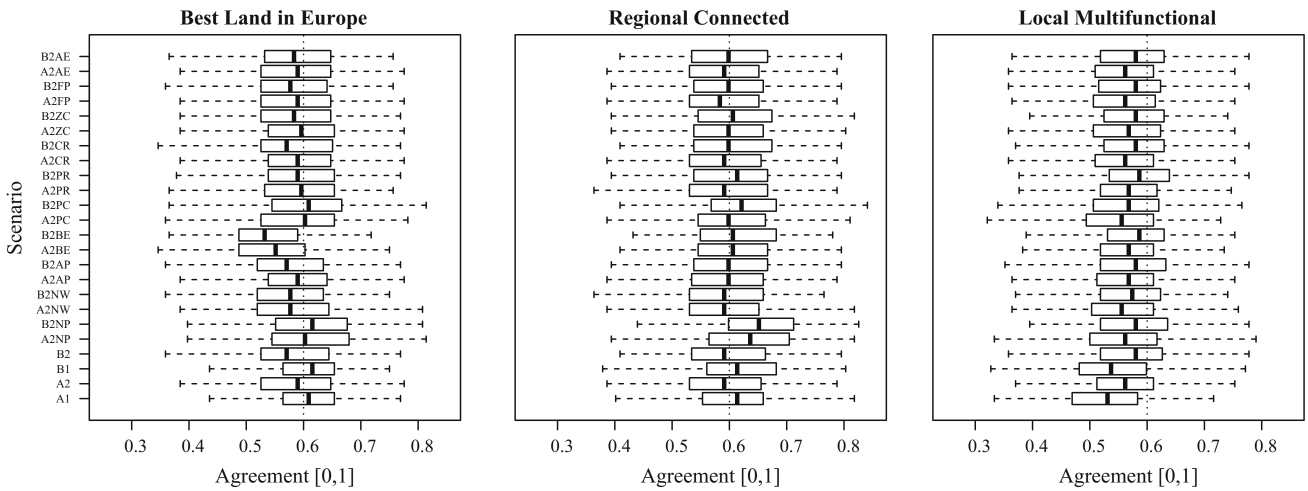



**Fig. 1** Result of matching desired and projected change in model variables (a value of 1 means full agreement). The *boxplots* are based on the 231 administrative regions as individual data points, without weighting them for area or population. The scenario names are explained in Table 1

## Results

### Pathways to the visions

In Fig. 1, we provide an overview of the agreement between the 24 land-use projections and the desired changes according to each of the three stakeholder visions. Our results indicated that the median level of agreement across regions exceeded the 60 % threshold for nine scenarios for the vision *Regional Connected* and six scenarios for the vision *Best Land in Europe*. These projections appeared therefore to be candidate pathways. However, when these scenarios were subjected to the land area and population criteria described in "Identifying pathways" section, we identified only five pathways to *Regional Connected* and two pathways to *Best Land in Europe*. We did not identify any pathway to the vision *Local Multifunctional*. Out of the 24 scenarios considered in the simulations, the *B2 Nature Protection* (B2NP) and the *B2 Payments for Carbon Sequestration* (B2PC) policy scenarios were pathways to *Regional Connected* and *Best Land in Europe*, while the *B1, A2 Nature Protection* (A2NP) and *B2 Payments for Recreational services* (B2PR) scenarios were pathways to *Regional Connected*. Given our assumptions to discover pathways, we could not identify any pathway under an A1 global development scenario. In the "Discussion" section, we discuss how different analytical assumptions can influence our results.

To analyse how different model variables contributed to the estimated level of agreement, we derived heat maps indicating how frequent (based on the number of regions) the projected change in a model variable is in agreement with the desired change for the four global developments and all pathways in Fig. 2. In Figures S4 and S5, results for all scenario projections, as well as results for model variables, in strong disagreement are shown. Our results suggest that the variable *crop yield* (aryd) increased as desired in all three visions, regardless of the scenario investigated. In addition, the variables *growth of peri-urban area* (peri) and *contribution of abandoned agricultural land to wilderness* (wild) changed in agreement with the vision *Regional Connected* regardless of the scenario.

There were few variables that changed in agreement with the visions only under particular scenario conditions, thereby explaining why some scenarios were pathways. For the vision *Regional Connected*, the variables *extent of arable land* (arab) and *extent of semi-natural area* (natu) explained why the *B1, A2 Nature Protection* and *B2 Nature Protection* scenarios were pathways to this vision. Similarly, for the *B2 Payments for Carbon Sequestration* scenario the *carbon sequestration in forest biomass* (cseq) and *dead wood* (ddwd) variables explained why this scenario was a pathway to the vision *Regional Connected*. Finally, for the *B2 Nature Protection* to *Regional Connected* scenario the *connectivity index of (semi-) natural area* (conn) was an important variable. The same set of variables was also important for the two identified pathways to *Best Land in Europe*.

None of our identified pathways showed full agreement for all variables with any of the visions. Always there were model variables that were in (strong) disagreement with the visions. For all visions, the desired and projected changes for the *extent of urban area* (urba) and for *crop diversity* (shan) were in disagreement for many regions and scenarios. The forest-related variables *carbon sequestration in forest biomass* and *dead wood* were also frequently in strong disagreement. Another model variable that was frequently in strong disagreement was *connectivity index of*

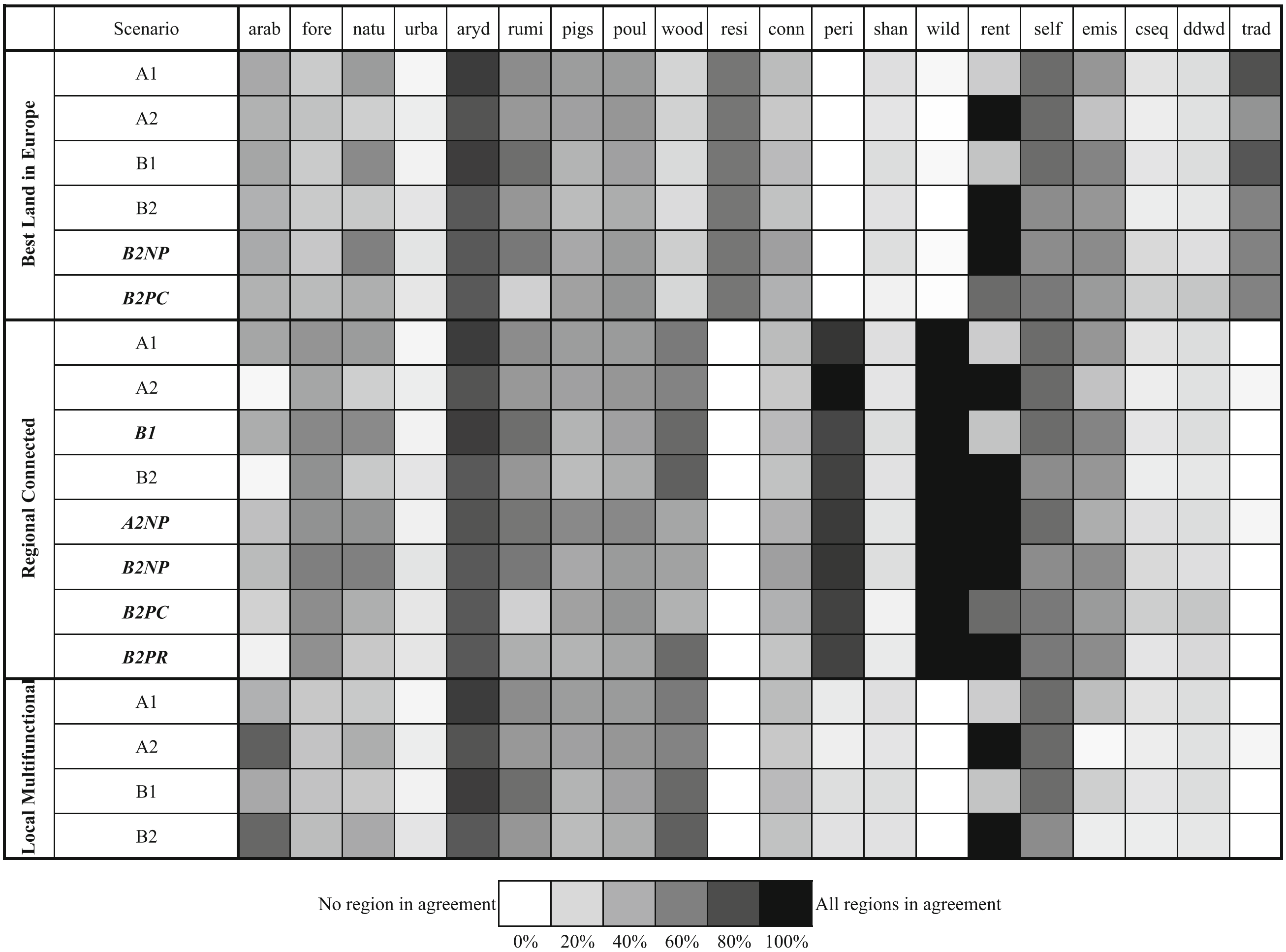
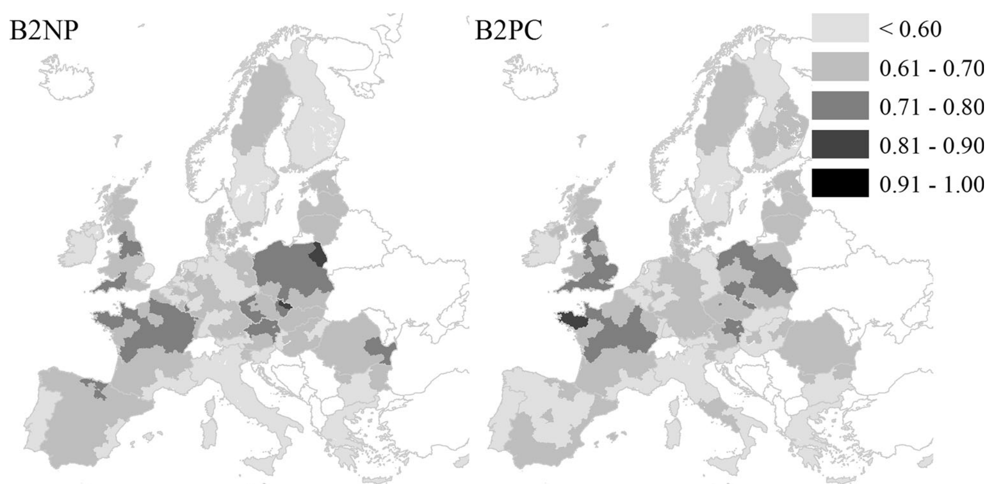



**Fig. 2** Heat maps indicating the frequency (based on the number of regions) a model variable is in full agreement with the visions for the global development scenarios and pathways (pathways are indicated in *bold*). Abbreviations are explained in Tables 1 and 2

**Fig. 3** Maps showing the level of agreement for the pathways to *Best Land in Europe*




(*semi-*) *natural area*. While these model variables were desired to increase in all three visions (see Table 2), they were generally projected to decrease according to the models, and none of the policy options brought them to the desired increase. Disagreements were less pronounced for the *Nature Protection* and *Payments for Carbon Sequestration* scenarios.

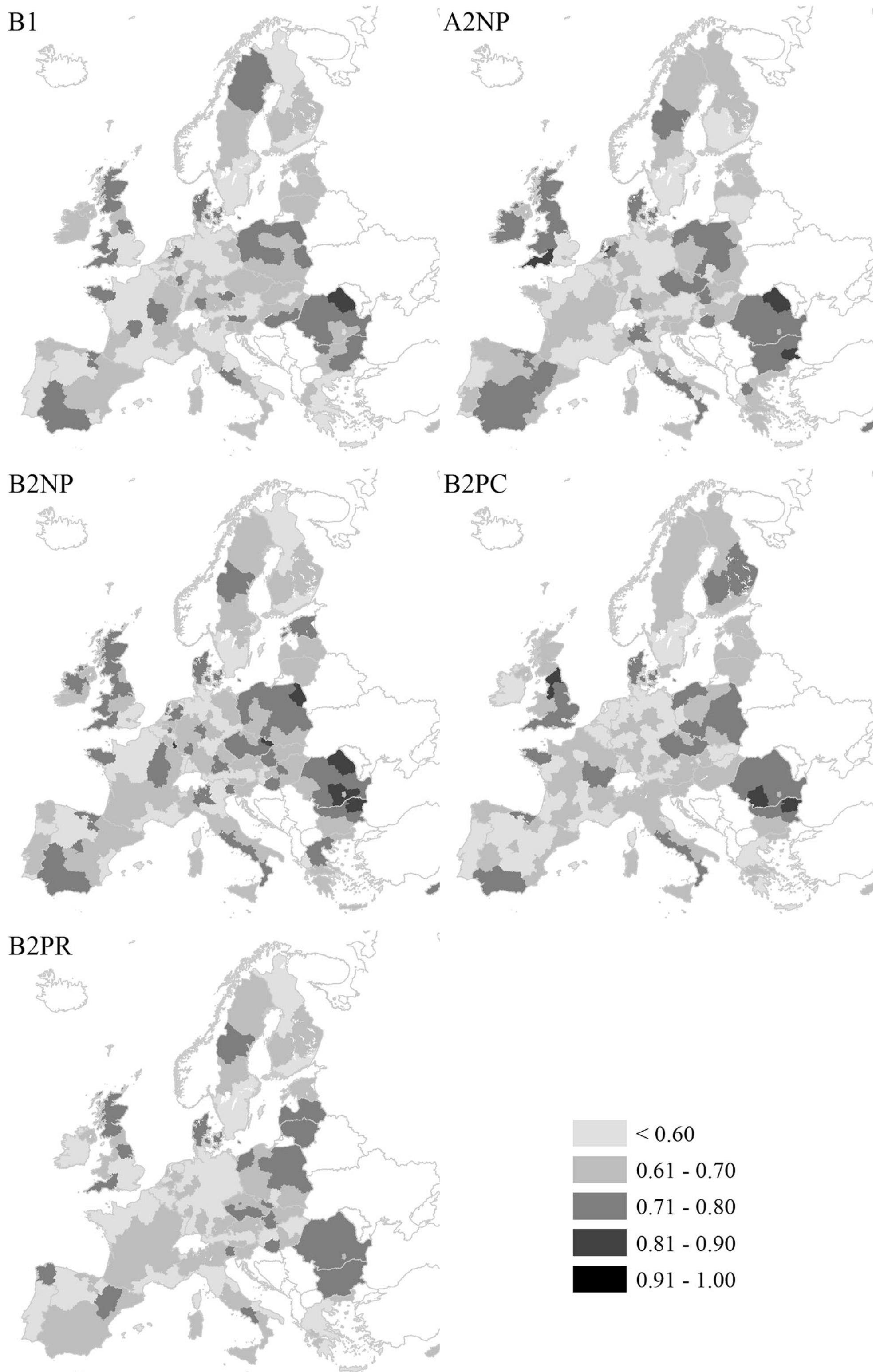



**Fig. 4** Maps showing the level of agreement for the pathways to *Regional Connected*

## Spatial patterns in pathways

To investigate regional patterns in the pathways, we mapped the agreement for pathways (Figs. 3, 4) and developed heat maps for all scenarios for clustered regions (by country, rurality class and environmental zone; Figure S6). Strikingly, the Baltic countries, Cyprus, Denmark, Bulgaria, Czech Republic, Hungary, Poland, Slovakia, Slovenia, Spain, northern Sweden, as well as several regions in the UK almost consistently agreed with more than 60 % with the desired land-use changes according to *Regional Connected*. For *Best Land in Europe,* we detected different patterns: both the *B2 Nature Protection* and *B2 Payments for Carbon Sequestration* pathways were in agreement with the visions in the Baltic countries, Denmark, Czech Republic, Poland, Romania, as well as western and central parts of France and most regions in the UK.

For *Regional Connected,* we found that many regions in Austria, Belgium, Germany, Greece and Portugal, southern Sweden and northwest and southeast France agreed with less than 60 % with the vision, regardless of the pathway investigated. Interestingly, Germany, Greece and Portugal were also generally in low agreement in pathways to *Best Land in Europe*. However, this did not apply to Austria, Belgium and France where land use generally developed in agreement with *Best Land in Europe*. Conversely, while land use generally developed in agreement with *Regional Connected* in Cyprus, Italy, Slovakia and Slovenia, there was low agreement for these countries with *Best Land in Europe*. We discuss possible reasons for these spatial patterns in "Implications for land use" section.

### Sensitivity analysis

Our sensitivity analysis (Figure S7) showed that the identification of pathways strongly depended on the assumed thresholds to define pathways. In cases where we applied stricter thresholds, no pathways could be identified to any of the visions, while in cases with less strict criteria, we detected a large number of pathways to all three visions. Interestingly, when reducing the stringency of the criteria to identify pathways, we identified nine pathways to the vision *Local Multifunctional*, but most of these pathways were not pathways to the two other visions.

## Discussion

### Implications for land use

Plausible scenarios of future land use derived from model projections may differ from what is actually desired by society, and identifying such mismatches can contribute to identifying policies to resolve them. We developed an analytical framework that links stakeholder visions of future land use to model-based projections of possible land-use changes according to four scenarios of possible future global developments and a range of policy options towards 2040. While the visions represent normative views on desired developments, the projections describe plausible developments of the near future, taking into account the main driving factors of land-use change. These two fundamentally different approaches of exploring the future of land use in Europe were brought together by comparing the endpoint of the modelled projections with the target of the desired visions. We considered as pathways those combinations of global developments and policy interventions that were leading to land-use futures that closely corresponded to multiple land-use dimensions of the defined visions.

When applying the framework, we identified five pathways to the vision *Regional Connected*, two pathways to the vision *Best Land in Europe*, but no pathways to the vision *Local Multifunctional*. The *B2 Nature Protection* and *B2 Payments for Carbon Sequestration* policy scenarios represented pathways to *Regional Connected* and *Best Land in Europe*. Both of these policy scenarios pose restrictions on the expansion of agricultural land in favour of more space for nature, which is also better connected with green corridors, and this fact explains their comparable results. We identified three additional pathways leading to *Regional Connected*. The policy options *A2 Nature Protection* and *B2 Payments for Recreational services* impose restrictions on land-use changes, bringing these closer to the desired land-use futures. In the *B2 Payments for Recreational services* policy scenario, payments are introduced for ecosystem services. Due to such payments, there is a marginal reduction in arable lands in favour of more grassland. In contrast, the *B1* global development scenario is a pathway, because in the assumed global development, growth of urban areas is restricted to designated areas, which limits peri-urban growth. Trade liberalisation triggers the import of feedstuffs, which leads to increasing livestock densities. Trade liberalisation also causes lower prices of agricultural outputs, which are offset by higher yields, partially due to concentration of agricultural production on less but more productive land. Abandonment of agricultural areas contributes to wilderness as the natural and forest areas expand. Wood production in forests increases to meet the increasing societal demand for wood products.

We observed interesting differences between member states as regards to the pathways. For example, the projected land-use changes in Austria, Belgium and France were in line with the desired changes according to *Best Land in Europe*, but not to those in *Regional Connected.* A possible explanation may be the intensity of the current land use in these countries (Plutzar et al. 2015), where fertile lands (or "best lands") are already used for agricultural production, which is much in line with the future land use according to *Best Land in Europe*. Interestingly, we found that projected land-use change in the Baltic countries, Czech Republic, Poland and Romania were generally in line with both the visions *Regional Connected* and *Best Land in Europe*. Land-use changes in these countries have already in the recent past shown patterns of both intensification in areas suitable for farming, and dis-intensification and cropland contraction in more marginal areas (Jepsen et al. 2015; Stoate et al. 2009), in line with the changes desired by both visions.

While we identified pathways to *Regional Connected* and *Best Land in Europe*, there were no pathways identified to *Local Multifunctional*. The main reason for the absence of pathways to *Local Multifunctional* is the incapability of the models to project all aspects of multi-functional land use at the local scale. All models, except Dyna-CLUE, operate at the level of administrative regions or larger entities and do not capture well the local patterns as envisioned in *Local Multifunctional* where more than one land use would be required locally. A second reason may be that *Local Multifunctional* requires a different set of policy options than those analysed in our study. We found several pathways to this vision in our sensitivity analysis. These pathways represent multiple policy options linked to the *B2* global development scenario. Similar to the pathways to the two other visions, this suggests that pathways to *Local Multifunctional* can be found with appropriate policy interventions in European land use, despite global trends. Yet, the policy options for which pathways could be identified to *Local Multifunctional* differed in most cases from the policy options that led to pathways to the two other visions. Furthermore, recent land-use changes show patterns that are more in line with the two other visions, with traditional farming landscapes, arguably the land system most closely resembling *Local Multifunctional*, rapidly disappearing across Europe (Fischer et al. 2012). Both push and pull factors contribute to the disappearance of these landscapes. On the one hand, better livelihood opportunities in urban areas, a disinterest of the younger generation in farming and the decreasing profitability of farming in more marginal regions (where most traditional farming landscapes are found), result in outmigration and sometime rural exodus (Fischer et al. 2012; MacDonald et al. 2000). On the other hand, increasing globalisation of agricultural markets and the pressure to enlarge farming operations to remain competitive pose major problems for traditional farming (van Vliet et al. 2015). Moreover, the EU accession of countries in Central and Eastern Europe has contributed to ongoing intensification trends and abandonment of marginal areas, both exacerbating the loss of traditional farming landscapes (Jepsen et al. 2015). Policies can affect these factors, at least to certain extent, and we speculate that the potential policies leading to *Local Multifunctional* would need to be radically different from policy options we considered in our analysis and to focus substantially more on maintaining and strengthening links between society and nature at the local scale (Fischer et al. 2012), to bring about the desired changes. Given that land-use trajectories are highly path dependent (Jepsen et al. 2015), it may be difficult to get closer to the vision *Local Multifunctional* without major shifts in land management paradigms.

Our analysis provides insights into the individual factors that contribute to the degree of agreement of the scenario projections with each of the visions. However, these results should not be considered in isolation but rather in connection with each other and cannot be used to identify single factors that decision-makers should address to reach a vision. For example, abandonment of agricultural land positively contributed to increasing nature areas, as desired according to the visions. However, stimulating abandonment all across Europe would mean a decrease in self-sufficiency of the EU and could lead to displacement of land use and feedbacks in the economic system. Such feedbacks are considered by the land-use models used here and explain why it may be difficult to reach the visions if these feedbacks are accounted for.

## Reflections on the approach

Stakeholders are increasingly involved in land-use modelling and scenarios construction (e.g. van Berkel and Verburg 2012; Hewitt et al. 2014; Palacios-Agundez et al. 2015; Haatanen et al. 2014). Yet, few attempts have been made to date to link desired land-use futures with explorative scenarios. Our approach can be considered as a variant of backcasting, which is recently also relying on forward-looking projections run by simulation models (van Vliet and Kok 2015). As our approach is to our knowledge applied here for the first time, we also reflect on the approach itself and identify avenues for improvement.

Firstly, we identified model variables based on statements made by stakeholders, but these model variables were not used when eliciting the visions. Pérez-Soba et al. (2015) asked stakeholders to imagine the future landscape they wished to live in and offered them elements to help describe that future. These elements related to land use in Europe, but did not include all variables available from the land-use models. From the perspective of the land-use models, a larger set of variables could have been used to characterise the desired land-use futures, although this comes at the cost of complexity which could be a barrier when eliciting visions. In contrast, stakeholders also included elements in their visions for which the land-use models did not provide variables (e.g. energy, water and transport). The pathways we identified could therefore not address all elements included in the three visions. To account for the multi-scale character and multiple dimensions of future land use, it would be recommended to better align the modelling and visioning processes such that both cover all relevant aspects to ensure the pathways provide a balanced representation towards future land systems.

Secondly, scenario definition and elicitation of the visions were done in parallel and largely independently. The fact that we identified only a few pathways to desired land-use futures suggests that the scenarios that were analysed may be too conservative or that the visions defined by stakeholders are too radical and visionary. Moreover, the policy options addressed may not have covered those interventions needed to reach the visions. The first issue could be overcome by developing more extreme scenarios that better cover the uncertainty in global development. Likewise, considering a different set of policy scenarios, or introducing iterations of scenarios with incremental policy changes until the desired goals are reached (Robinson et al. 2011; Seppelt et al. 2013) could be used to better align scenarios and visions. Regarding the second issue, a stricter linkage between the process to formulate policy scenarios and the process to elicit visions would have permitted the definition of more targeted policy scenarios that could be more appropriate to address stakeholder wishes on future land use.

Thirdly, we had to make several strong assumptions to be able to decide when a scenario would be a pathway to a vision. We checked the impact of our assumptions using a sensitivity analysis. The results suggest that the number of pathways was highly dependent on the decision rules applied, which in turn depends on the trade-offs that the stakeholders are willing to accept to reach a vision. Furthermore, we assumed that a model variable had changed in time when a deviation of 5 % was found compared to the present situation. However, what is seen as a significant change could be different depending on the magnitude of changes in the model variables as envisioned by the stakeholders. The analysis revealed that the results were sensitive to the type of vision, i.e. no effect of this assumption on the identification of pathways to *Local Multifunctional*, but on the contrary this assumption did reveal medium to strong impacts on the identification of pathways to *Best Land in Europe* and *Regional Connected*. In this paper, the decision rules needed in the various steps to identify pathways to visions of future land use were defined in a simple and reproducible manner. In future work, we suggest a stronger rationale behind these assumptions.

These three issues relate to the process on how to better link stakeholder visioning processes and exploratory scenario modelling. Reflecting on our approach, we think it would be beneficial to link more tightly the different modelling steps and the elicitation of the visions of future land use, which would result in fewer assumptions needed when identifying pathways. However, the linkage should not be too stringent either, because models represent a simplification of reality and often allow for only a limited set of policy options to be analysed. Such limitations should not impede the creativity and freedom of stakeholders to express their desired future land use.

It is important to consider that the agreement between scenario projections and visions is based on changes in land use rather than on the current or future state of land use. This difference is important, because some regions may currently already be close to the desired state, although our results may suggest a low level of agreement in 2040. A low-level agreement may still indicate a good fit of the situation with desired land use, while a high fit does not necessarily mean that land use in that region reaches the desired vision. Future analysis may focus on both the state and change of land use to obtain a more complete picture.

Our approach to identify pathways to desired land-use futures relied on model projections of land use over several decades. We assessed the changes in land use between current land use and land use in 2040, assuming policy interventions would occur at the onset of our observation period. Future research could assess how the timing of policy interventions would affect the identification of pathways. Furthermore, our models do not include regime shifts in land systems, such as shock events (e.g. economic crises, rapid institutional change), technological breakthrough or other changing boundary conditions. Hence, it is obvious that land use may develop differently than projected. Likewise, stakeholders (and their successors) may change their perceptions and priorities over time, leading to changing visions. This means that if society would like to move to any of the three envisioned land-use futures, pathways should be evaluated repeatedly to verify whether the changes in land use are in line with the desired changes and to adjust policies where needed in an adaptive management process (Lindenmayer and Likens 2009; Haasnoot et al. 2013).

## Conclusions

This paper presents a novel approach to link stakeholder-based visions of future land use with model-based projections of how land use may change in Europe. We analysed the projected future land use for four global development scenarios and found that land-use changes in a globalised world generally showed better agreement with one of the visions (*Regional Connected)* as compared to a future world with a more regionally fragmented development. In a regionally fragmented world, however, policies have the ability to change the development of land use such that it is more in line with land-use futures desired by society. We also found that none of our pathways were fully in line with the visions. This implies that the identification of pathways to a desired future land use is subject to the trade-offs that stakeholders (or society) should be willing to accept. Models can provide insight into land-use changes and reveal potential impacts to help stakeholders make well-informed decisions. Linking stakeholder-based visions to quantitative, large-scale land-use modelling is feasible and is best conducted in an iterative manner. We believe our approach to combine explorative scenarios with normative visions represents a promising avenue for foresight studies on land use.

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