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Identifying pathways to visions of future land use in Europe

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Abstract

Plausible scenarios of future land use derived for 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 (EU) 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 are 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 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

1 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).

Scenario analysis is considered an important foresight technique to support strategic decision making while dealing with uncertainty (van de Heijden 2005; Pérez-Soba and Maas, 2015). Scenario analysis helps to characterize 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 answer questions on what *could* happen. There is however another group of scenarios that aims to answer the question what *should* happen (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 foresight 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 modeling, 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 land use planning (Haslauer 2015). Yet, backcasting has not been used in large-scale land-use foresight studies, presumably because of the complexity of land-use dynamics.

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) as the credibility of explorative scenarios, as perceived by stakeholders, is combined with the perceived legitimacy and saliency of normative visions (Rounsevell and Metzger 2010; Pérez-Soba and Maas, 2015). Recently, Pérez-Soba et al. (2015) elicited normative visions of future land use in the European Union (EU) for the year 2040 in a participatory stakeholder process. This process resulted in three distinct land use visions, all having multifunctionality at their core, but differing in the spatial scale at which multifunctionality 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.

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 (i) to develop an approach to link quantitative model projections to qualitative visions statements by stakeholders, (ii) to apply the approach to the three visions of land use in Europe, and (iii) to discuss the approach as a decision support tool in land use policy and planning.

2 Methods and data

2.1 Data on land use projections

To identify pathways to the three future land-use visions, we used simulations from Lotze-Campen et al. (2013) and Verburg et al. (2013), 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. Selected outputs from these two models were provided to 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 forest production. Simulation results from these global models were used as input to the agricultural economic model CAPRI and the forest resource projection model EFISCEN. 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 details on and 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, 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 and Table S2), which we used for our analysis. Projections results were used at the level of administrative regions (Nomenclature des Unités Territoriales Statistiques - NUTS level 2).

<<Table 1>>

While the process to define visions and the design of the exploratory scenarios to be addressed by the modelling was loosely linked by focussing on similar land use types, the detailed development of the modelling framework and the definition of the scenarios was conducted mostly independent from 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.

2.2 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 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 dataset. 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 model variables were, therefore, used for subsequent analyses.

2.3 Matching desired and projected change

After selecting the model variables, we determined in which direction each of the selected variables should change over time according to the three visions, and how they 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. We added a second weight (*w2*) to take into account that stakeholders expressed repeatedly that a variable should change strongly. As it was not clear what a strong change would entail according to the stakeholders, we gave larger weight to model variables for which stakeholders indicated a strong change. The desired changes for the three visions are shown in Table 2.

Stakeholder visions indicated distinct spatial distributions for the different land uses. As regards 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. To identify productive regions, we used the agricultural productivity calculated by CAPRI as a proxy for each region in our dataset. 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, and a -1 for Southern Europe and 0 for 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 minimal 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.

2.4 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. 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:

$$agreement_{\mathrm{i,j,l}} = 1 - \frac{\sum_{\mathrm{k=1}}^{\mathrm{n}} w1_{\mathrm{k}} \times w2_{\mathrm{j,k,l}} \times mvar_{\mathrm{i,k,l}}}{2 \times \sum_{\mathrm{k=1}}^{\mathrm{n}} w1_{\mathrm{k}} \times w2_{\mathrm{j,k,l}}}$$

where *w1* and *w2* denote weights (see section 2.3), *mvar* 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). This formula results in values in the range [0,1]; a value of 1 means that a scenario projection is in full agreement, 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 (i) 70% between a scenario projection and a vision, (ii) 60% and apply to >50% majority of the population and land area; (iii) 60% and apply to a two third majority of the population (not land area), (iv) 60% and apply to a two third majority of the land area (not population), and (v) 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%.

3 Results

3.1 Pathways to the visions

Matching desired and projected changes in future land use indicated that most scenario projections agree with about 60% of the visions and that there were no scenario projections that were in full agreement with any of the visions at the European level (Figure 1). When adding the criteria on population and land area, we identified five pathways to *Regional*

Connected, two pathways to *Best Land in Europe*, but no pathways to *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*. We did not identify any pathway in a world developing according to our A1 global development scenario.

<<Fig1>>

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 Figure 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 *extent of arable land* and *extent of semi-natural area* explain why the *B1 scenario, A2 Nature Protection* and *B2 Nature Protection* were pathways to the vision *Regional Connected*, while for the *B2 Payments for Carbon Sequestration* the main variables were *carbon sequestration in forest biomass* and *dead wood*. The *connectivity index of (semi-) natural area* was also an important variable in the *B2 Nature Protection* to *Regional Connected*. The same set of variables was also important for the two pathways to *Best Land in Europe*.

<<Fig2>>

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 change for the forest-related variables *carbon sequestration in forest biomass* and *dead wood* were frequently in strong disagreement. Another model variable that was frequently in strong disagreement was *connectivity index of (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.

3.2 Spatial patterns in pathways

To investigate regional patterns in the pathways, we mapped the agreement for pathways (Figures 3 and 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 United Kingdom 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 United Kingdom.

<<Fig3>>

<<Fig4>>

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*.

Our sensitivity analysis (Figure S7) showed that the identification of pathways strongly depended on the assumed thresholds to define pathways. In case we would have applied more strict thresholds, no pathways would be identified to any of the visions, while if we would apply less strict criteria, we would detect a larger number of pathways to all 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.

4 Discussion

4.1 Interpretation of results

Plausible scenarios of future land use derived for model projections may differ substantially from what is actually desired by society and identifying such mismatches is important for 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 in 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 and which are also better connected with each other, and this fact explains their comparable results. We identified three additional pathways leading to *Regional Connected*. The policy options in these pathways impose restrictions on land use changes, bringing these closer to the desired land use futures.

We observed interesting differences between Member States with 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 interventions than those analysed in our study. 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). We therefore speculate that the potential policies leading to *Local Multifunctional* would need to be radically different from policy options we considered here, and focus substantially more on maintaining and strengthening links between society and nature at local scale (Fischer et al. 2012), in order 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 this type of processes is accounted for.

4.2 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 independent. 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 reach the visions. The first issue could be overcome by developing more extreme scenarios that better cover the uncertainty in global development including possible regime shifts. 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 more strict 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 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 are 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 necessary 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. Considering that our models do not include regime shifts in land systems, for example to shock events such as economic crises, rapid institutional change, or technological breakthrough, as well as changing boundary conditions, such as new value systems, 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 et al. 2009; Haasnoot et al. 2013).

5 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. Linking stakeholder-based visions to quantitative, large-scale land use modelling remains challenging, for it is difficult to find the right balance in connecting the two fundamentally different approaches. Nevertheless, we believe our approach to combine explorative scenarios with normative visions represents a promising avenue for foresight studies on land use.

Acknowledgements

This work has been funded through the EU 7th framework project VOLANTE (project number 265104). The authors thank Sergey Zudin, Elena Zudina and Simo Varis from the European Forest Institute for their help with data processing, Bep Schrammeijer from VU University for scenario simulations, as well as all partners of the VOLANTE project for their comments on the approach. Opinions expressed in this paper are those of the authors only.

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List of Figures

Figure 1

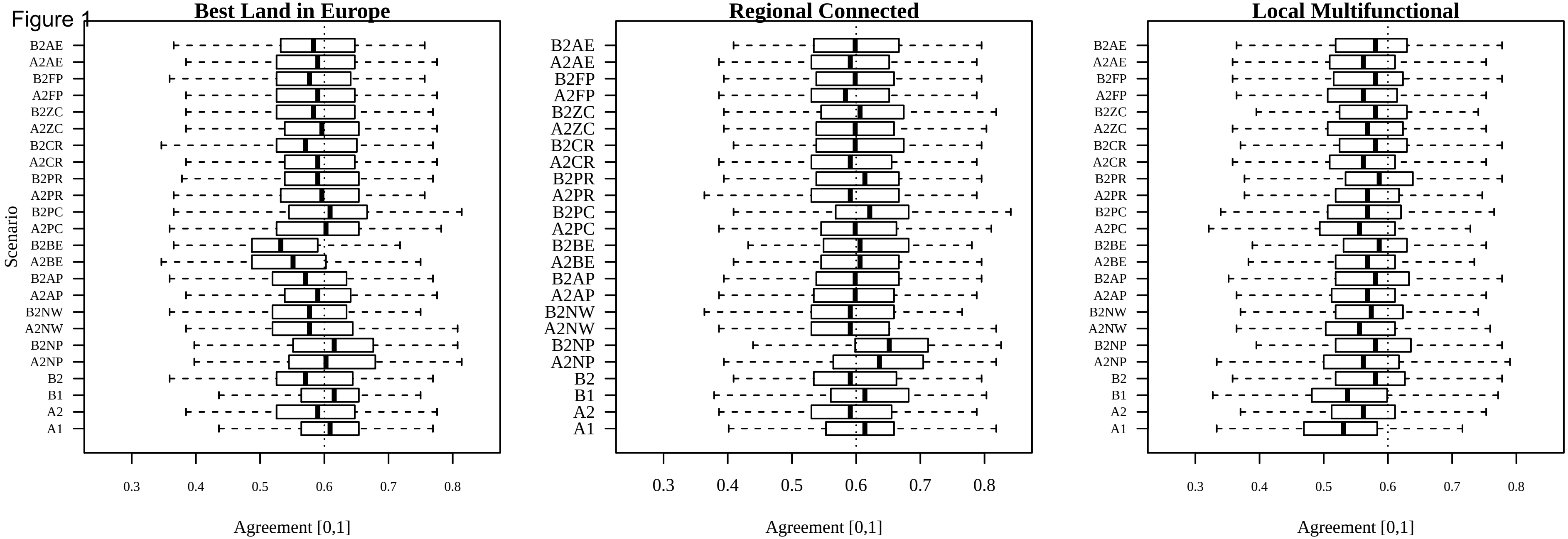
Best Land in Europe
Regional Connected
Local Multifunctional
Scenario
B2AE
A2AE
B2FP
A2FP
B2ZC
A2ZC
B2CR
A2CR
B2PR
A2PR
B2PC
A2PC
B2BE
A2BE
B2AP
A2AP
B2NW
A2NW
B2NP
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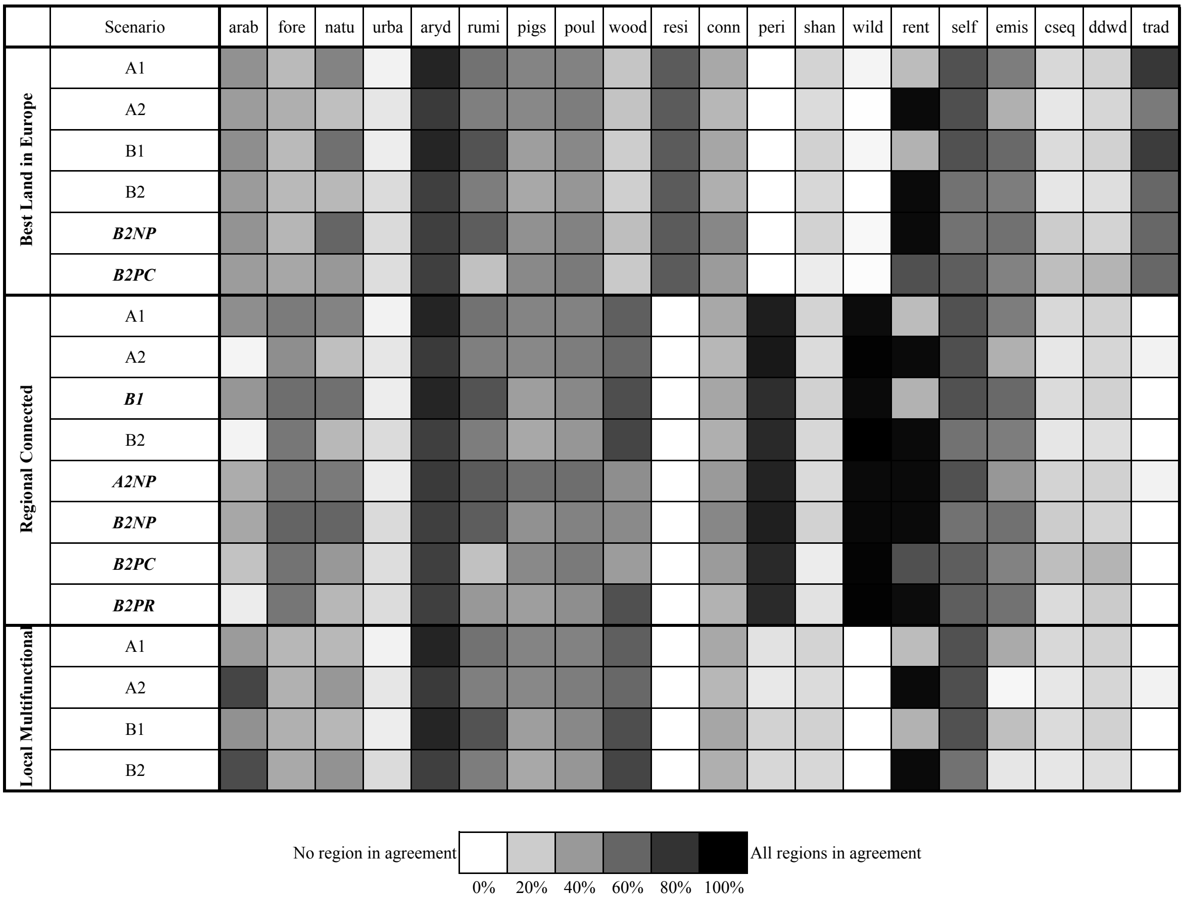
Figure 2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Best Land in Europe
A1
A2
B1
B2
B2NP
B2PC
Regional Connected
A1
A2
B1
B2
A2NP
B2NP
B2PC
B2PR
Local Multifunctional
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No region in agreement
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Figure 3

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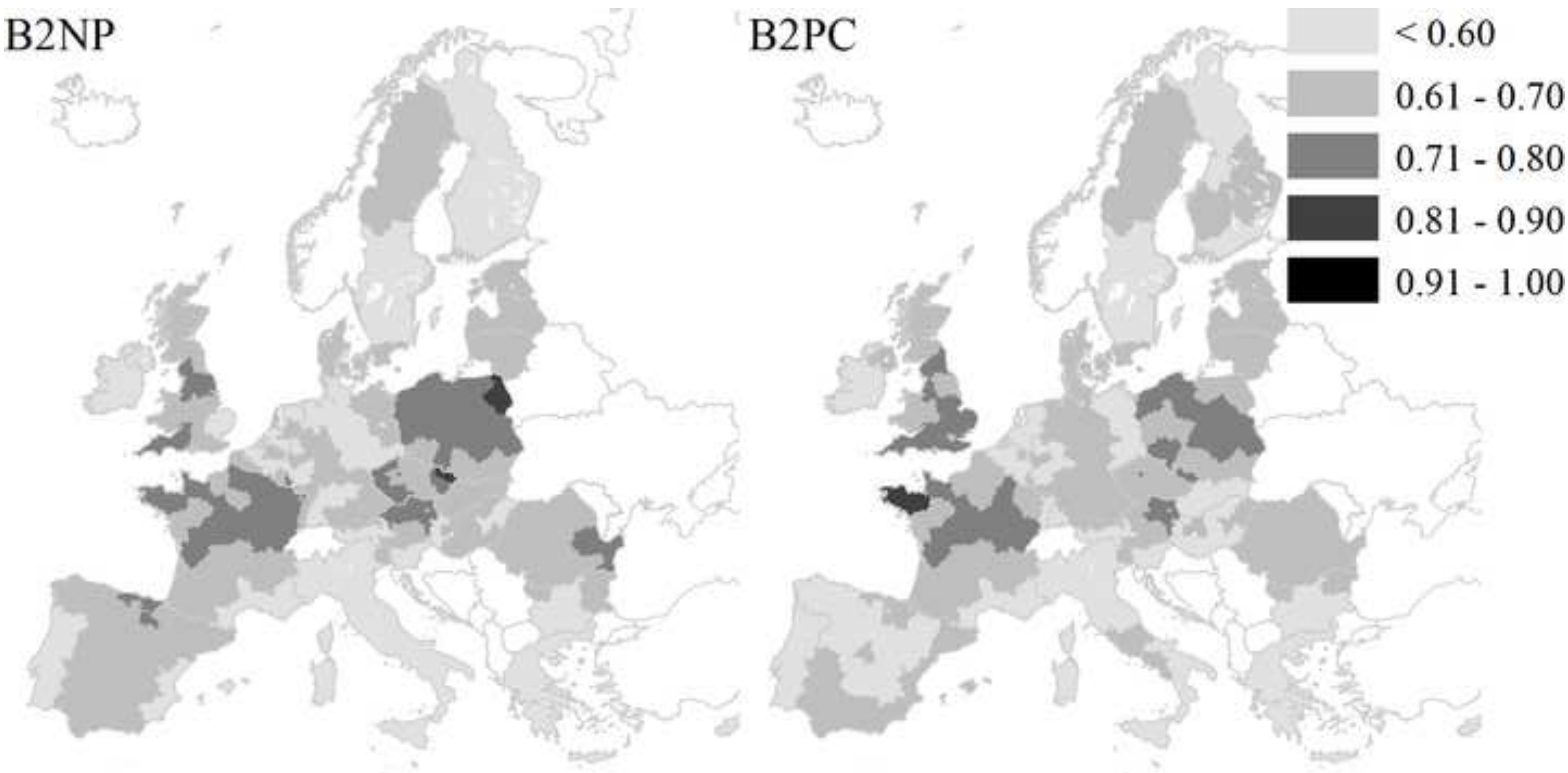

Figure 4

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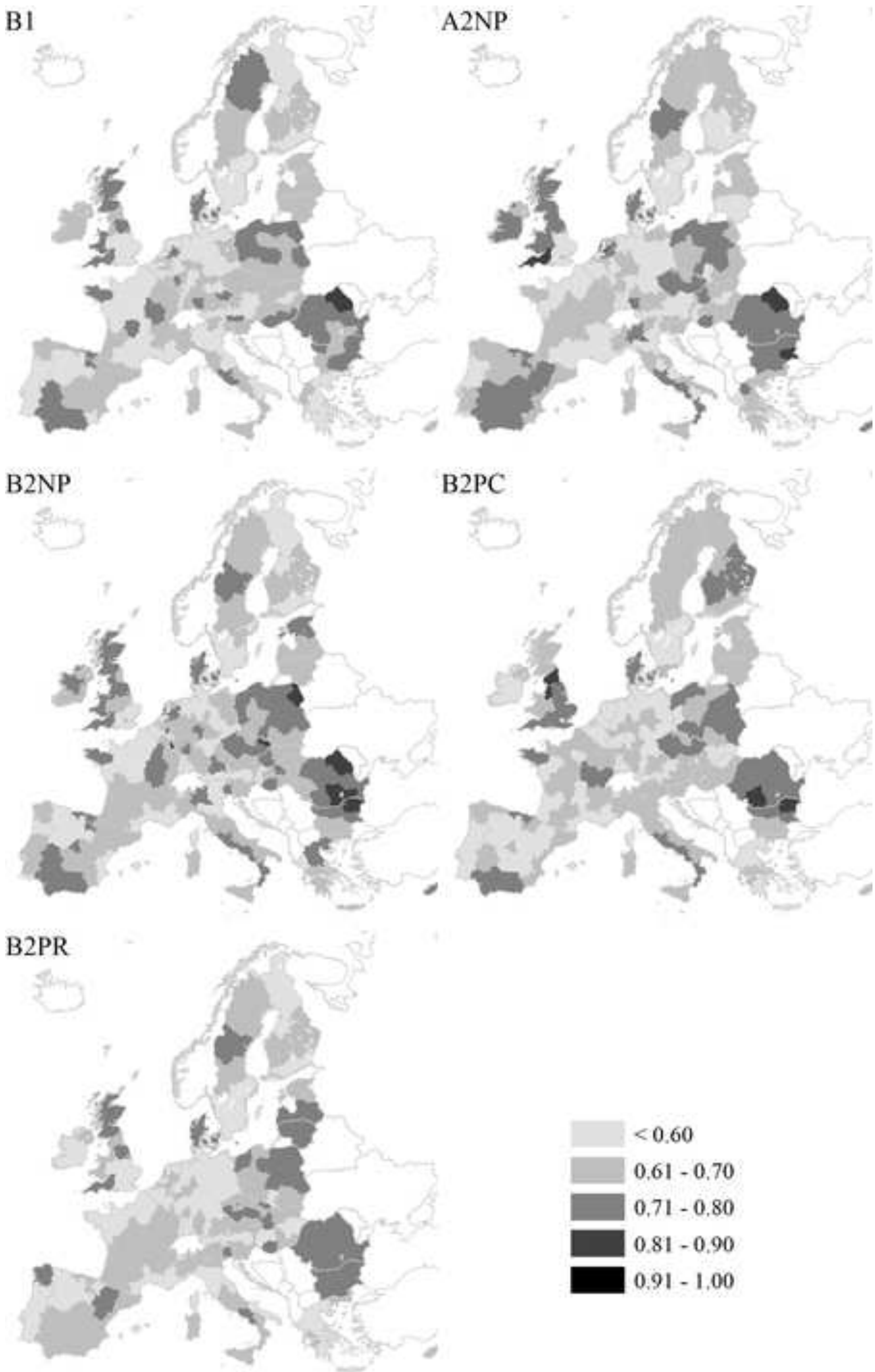

Tables

Table 1: Brief description of the scenarios. References to more detailed descriptions are given in Table S2 of the Supplementary Online Material.

#	Global development	Code	Scenario	Brief description of policy alternative
1	A1	A1	Global development	Globalized 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 of the application of nitrates from animal manure to prevent further ground 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 (i) 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 (ii) 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		

Table 2: Desired change (*d*) and weight (*w2*) of the model variables according to the three visions. The desired changes +1, 0 and -1 indicate whether a model variable is desired to increase, not change or decrease, resp. In case multiple desired changes are shown, a regional pattern was assumed. The *w2* indicates whether a model variable was desired to *change strongly* by the stakeholders. See text for details on assumed regional patterns and *w2*.

Attribute	**Variable**	***Abbreviation***	***Best Land in Europe***		***Regional Connected***		***Local Multifunctional***	
			d	***w2***	***d***	***w2***	***d***	***w2***
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

Electronic Supplementary Material Click here to download Electronic Supplementary Material Verkerk_pathways_SOM_submitted.docx

SUPPLEMENTARY MATERIAL

Identifying pathways to visions of future land use in Europe

Pieter J. Verkerk, Marcus Lindner, Marta Pérez-Soba, James S. Paterson, John Helming, Peter H. Verburg, Tobias Kuemmerle, Hermann Lotze-Campen, Alexander Moiseyev, Daniel Müller, Alexander Popp, Catharina J. E. Schulp, Julia Stürck, Andrzej Tabeau, Bernhard Wolfslehner, Emma H. van der Zanden

Contents

Table S1: Web links to model descriptions and scientific references.

Model	Reference	Factsheet
ReMIND/MAgPIE	Lotze-Campen et al. 2008; Leimbach et al. 2010	http://www.volante-project.eu/images/Factsheets/A16_Model_MAgPIE_REMIND.pdf
MAGNET	Woltjer et al. 2014	http://www.volante-project.eu/images/Factsheets/A17_Model_LEITAP_MAGNET_2015.pdf
EFI-GTM	Kallio et al. 2004	http://www.volante-project.eu/images/Factsheets/A21_Model_EFI-GTM.pdf
CAPRI	Britz and Witzke 2012	http://www.volante-project.eu/images/Factsheets/A19_Model_CAPRI.pdf
EFISCEN	Sallnäs 1990; Schelhaas et al. 2007	http://www.volante-project.eu/images/Factsheets/A20_Model_EFISCEN.pdf
Dyna-CLUE	Verburg and Overmars 2009	http://www.volante-project.eu/images/Factsheets/A22_Model_DynaCLue.pdf

Table S2: References to scenario descriptions.

#	Code	Scenario	Reference
1	A1	Global development	http://www.volante-project.eu/images/Factsheets/A1_Fact_sheet_Marker_scenario_storylines.pdf
2	A2		
3	B1		http://www.volante-project.eu/images/Factsheets/A2_Marker_scenario_model_implementation.pdf
4	B2		
5	A2NP	Nature protection	http://www.volante-project.eu/images/Factsheets/A5_VPA_Nature_Protection.pdf
6	B2NP		
7	A2NW	Nitrogen and water quality	http://www.volante-project.eu/images/Factsheets/A6_VPA_Nitrogen_and_water_quality.pdf
8	B2NW		
9	A2AP	Agricultural productivity increase	http://www.volante-project.eu/images/Factsheets/A7_VPA_Agricultural_increase.pdf
10	B2AP		
11	A2BE	Bio-based economy and bioenergy	http://www.volante-project.eu/images/Factsheets/A8_VPA_Biobased_economy.pdf
12	B2BE		
13	A2PC	Payment for carbon sequestration	http://www.volante-project.eu/images/Factsheets/A9_VPA_Payment_for_carbon_sequestration.pdf
14	B2PC		
15	A2PR	Payment for recreational services	http://www.volante-project.eu/images/Factsheets/A10_VPA_Payment_for_recreational_services.pdf
16	B2PR		
17	A2CR	CAP reform	http://www.volante-project.eu/images/Factsheets/A11_VPA_CAP_reform.pdf
18	B2CR		
19	A2ZC	Zoning for compact cities	http://www.volante-project.eu/images/Factsheets/A12_VPA_zoning_compact_cities.pdf
20	B2ZC		
21	A2FP	Flood protection	http://www.volante-project.eu/images/Factsheets/A13_VPA_CC_Flood_protection_.pdf
22	B2FP		
23	A2AE	Climate change mitigation	http://www.volante-project.eu/images/Factsheets/A14_VPA_CC_mitigation_and_agricultural_emission_taxes.pdf
24	B2AE		

Table S3: Selected model variables.

Attribute	Variable	Model	Description
Land cover extent	Extent of arable land	CAPRI	Acreage of all arable, vegetable and horticultural crops in percent of total land area. The variable also includes temporary grassland, fallow land and set aside.
	Extent of forest area	Dyna-CLUE	The forest area in percent of total land area, containing production forest, protected forest, and forest not currently harvested for other reasons. It does not include other types of natural vegetation, nor does it contain agro-forestry land cover types.
	Extent of (semi-) natural area	Dyna-CLUE	The area in percent of total land area of forests (see above) and all (semi-) natural vegetation types that are non-forest with the exception of small forest patches as occurring in agricultural landscapes. This class includes natural grasslands and scrublands.
	Extent of urban area	Dyna-CLUE	All built-up area (and other human fabric) area in percent of total land area. It includes continuous urban fabric, discontinuous urban fabric, industrial areas, commercial areas, road and rail networks, (air)ports, mineral extraction sites, dump sites, construction sites, green urban areas, sports facilities, and leisure facilities.
Land use management	Crop yield	CAPRI	Average yield per ha of all arable crops, included in variable 'extent of arable land'. The individual crops are weighted by acreage per crop and corresponding revenue per crop per ha in constant euros of 2010.
	Stocking density of ruminants	CAPRI	Stocking density of ruminants per fodder area (grassland plus fodder on arable land). Ruminants include dairy cows, suckler cows, male and female beef cattle, all calves and heifers and sheep and goats. The individual animals are aggregated by livestock units with 1 cow is 1 livestock unit.
	Stocking density of pigs	CAPRI	Stocking density of pig fattening per ha of arable crop
	Stocking density of poultry	CAPRI	Stocking density of poultry fattening per ha of arable crop
	Roundwood removals	EFISCEN	The amount of roundwood removed from production forests for material and energy use per ha forest
	Extracted logging residue and stumps	EFISCEN	The amount of logging residues (stem tops, branches) and stumps removed from production forests for energy production per ha forest
Land use pattern	Connectivity index of semi-natural area	Dyna-CLUE	This indicator gives the approximation of the connectivity potential of the landscape for species and the viability of smaller habitats within the landscape. It calculates the ease to reach larger sized areas of natural vegetation from smaller sized habitats, accounting for the land use types between the habitats. For example, an urban area is very difficult to migrate through as a species (high resistance), while permanent grasslands are much easier (low resistance).
	Growth of peri-urban area	Dyna-CLUE	Peri-urban growth, as opposed to urban sprawl/edge expansion of cities, is defined as outlying growth of built-up area (outside of urban cores).
	Shannon-index for crop diversity	CAPRI	Diversity index for agricultural crops, including grassland.
	Contribution of abandoned	Dyna-CLUE	Formerly agricultural land, converted to nature (semi-natural or forest cover) which forms part of a wilderness patch. The definition

	agricultural land to wilderness		of wilderness follows "Wild Europe: A Working Definition of European Wilderness and Wild Areas”
Land use services	Shadow value of agricultural land	CAPRI	Shadow price of land represents its opportunity cost (the value of the land in its next best alternative use). The average shadow price of land in a region, can be seen as an estimate of the economic value of land in that region and an indicator of generating income
	Production over domestic consumption for softwheat	CAPRI	Production over domestic consumption. Soft wheat was used as an indicator for self-sufficiency in food consumption in the EU.
	Global Warming Potential in agriculture	CAPRI	Emissions of greenhouse gases by agriculture expressed as a global warming potential (in CO_2 equivalents)
	Deadwood in forest	EFISCEN	The amount of standing and lying deadwood in production forests. Deadwood is an important indicator for forest biodiversity
	Carbon sequestration in forest biomass	EFISCEN	The annual amount of carbon removed from the atmosphere and stored in forest biomass. Carbon sequestration in forest biomass is important for climate change mitigation.
Global land impacts	Net-trade of agri-food products	MAGNET	The difference between export and import of agri-food products

Table S4: Overview of rurality classes and environmental zones.

Cluster	**Proportion of regions in which dominant (%)**	**Description**
		Rurality
Urban	3	High population density and high levels of Gross Domestic product (GDP). Low in agricultural land and very low in semi-natural vegetation.
Peri-urban	22	High population density and high levels of GDP. Regions include the tertiary sector, predominantly resulting in a relative small agricultural share of the total GDP. Regions are still characterised by a large, but progressively declining, percentage of land in use for primary production, with wide geographical differences.
Rural	43	Medium population density and average income with wide geographical differences. A large proportion of land is used for agricultural production with rural areas not always very distant from major urban centres.
Deep rural	33	Low population density and low average income.
		Environmental zones
North	7	Environmental stratification of Europe based on a selection of environmental variables (climatic variables, elevation data, indicators for oceanicity and northing)
Atlantic	33	
Continental	34	
Alpine	3	
Mediterranean	23	

Source: van Eupen et al. 2012

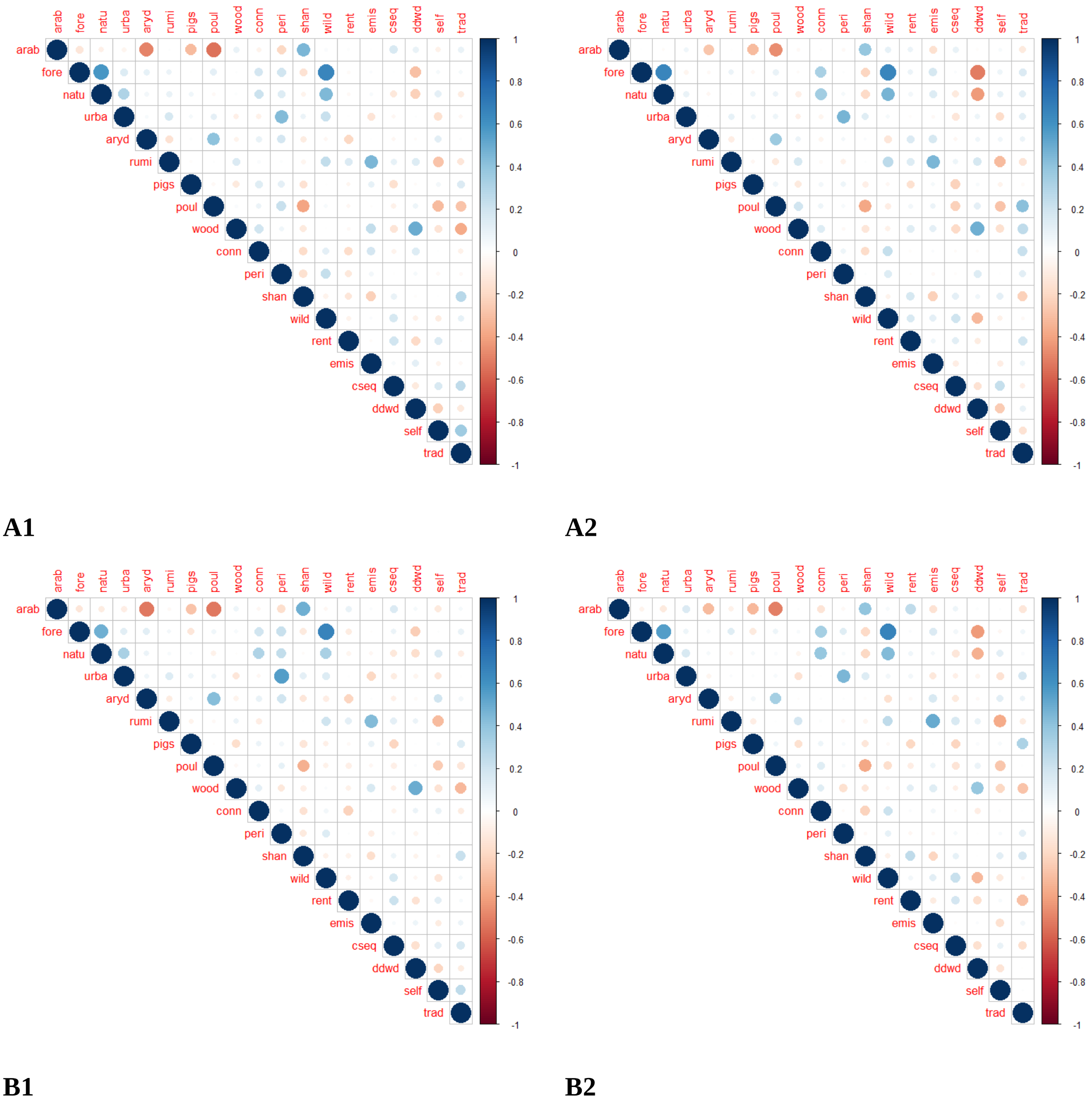

Figure S1: Correlation plots.

The correlation plots the selected model variables the four global development scenarios. Spearmann rank correlations were calculated based on the change ratio between 2040 and the base year for each model variable. The size of the circle denotes the strength of the correlations and the colour indicates whether the correlation is positive (blue) or negative (red).

Projected / Desired	-1	0	+1
-1	Agreement	Minor dis-agreement	Strong dis-agreement
0	Minor dis-agreement	Agreement	Minor dis-agreement
+1	Strong dis-agreement	Minor dis-agreement	Agreement

Figure S2: Schematic overview of matching projected and desired land use changes.

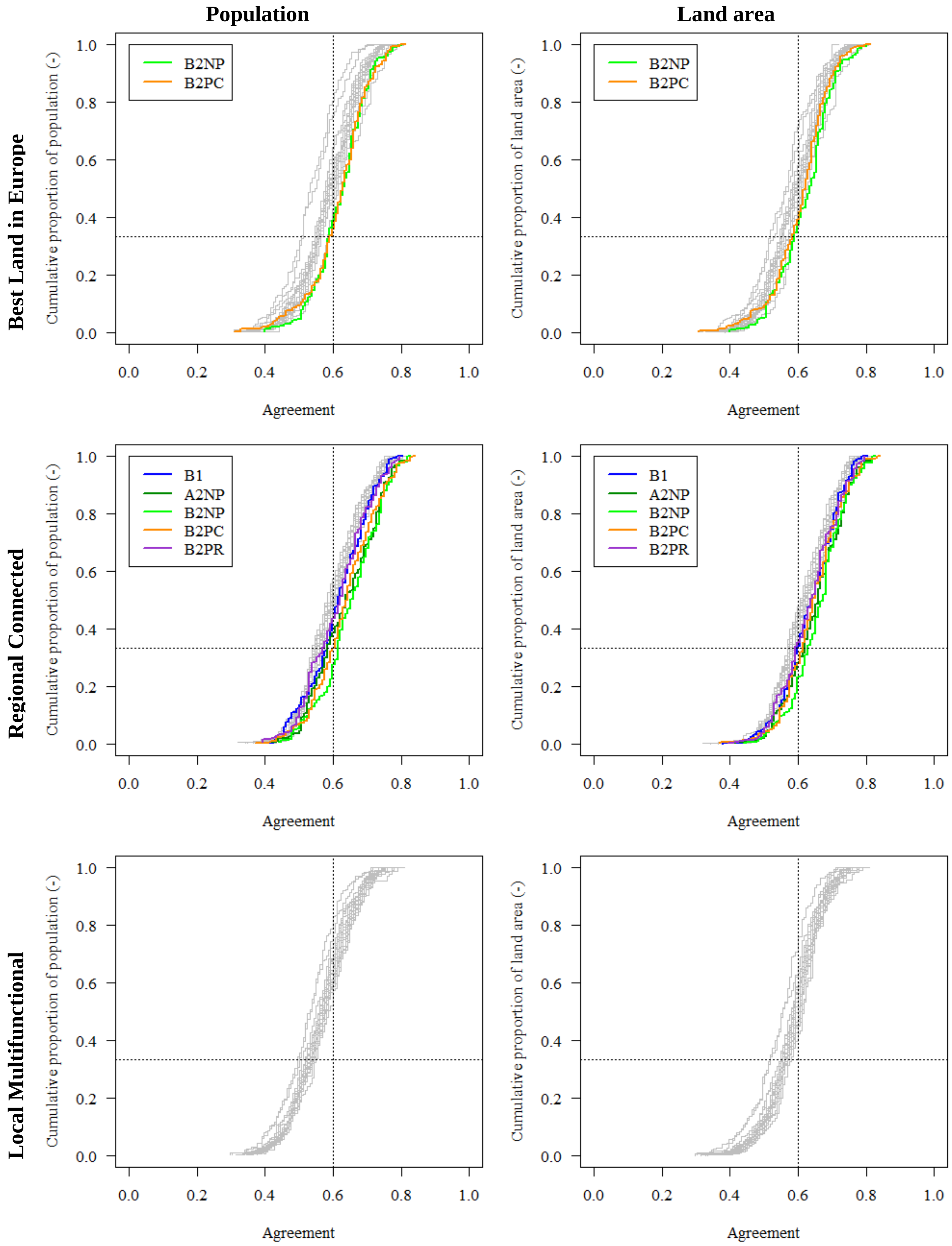

Figure S3: Pathways to the visions.
The pathways are shown in colour and non-pathways are shown in grey. The graphs show the cumulative proportion and land area (in columns) for different levels of agreement between model projections and the three consolidated stakeholder visions (in rows). The abbreviations of the scenarios are explained in Table 1.

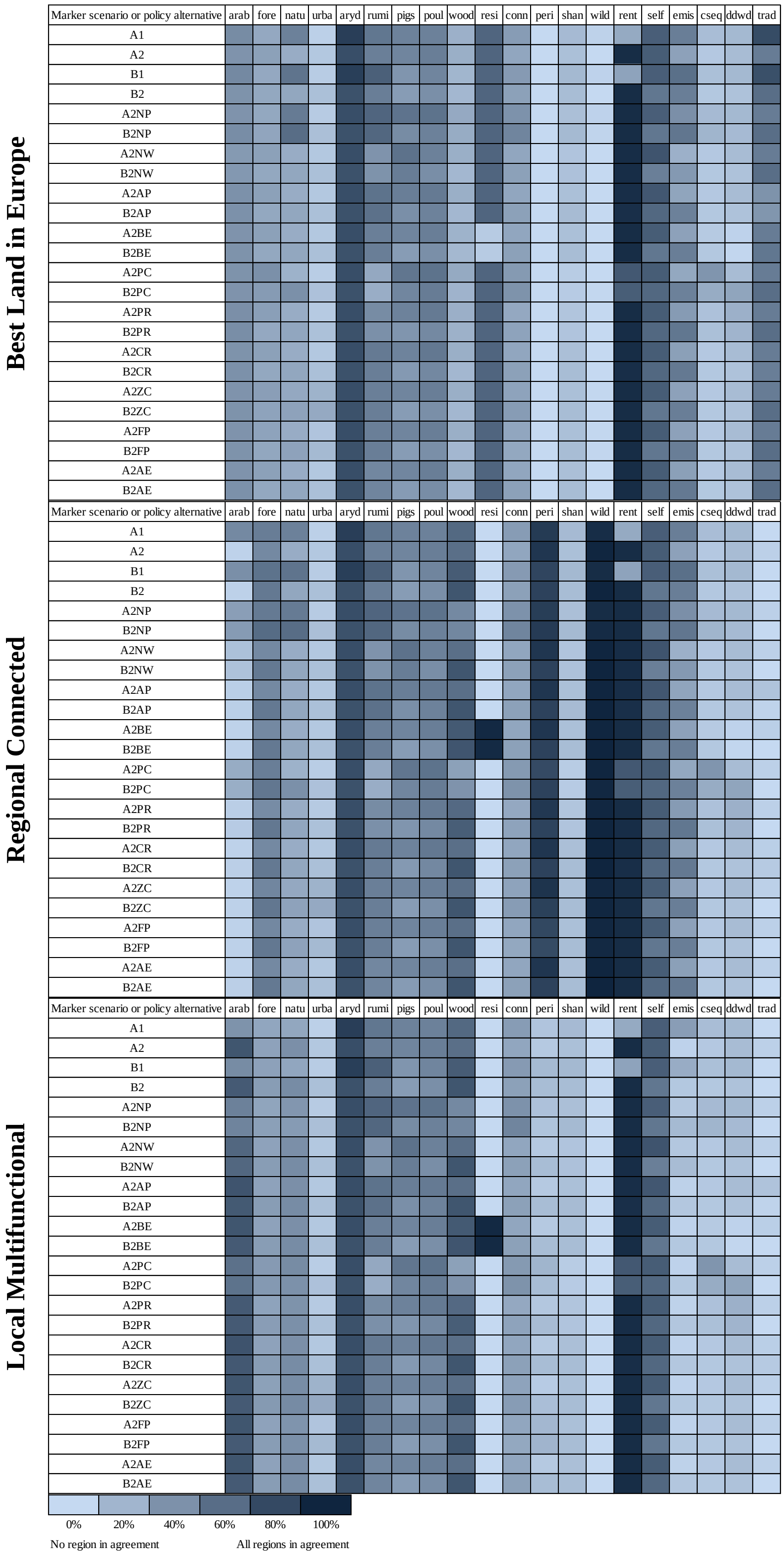

Figure S4: Heat maps for full agreement for model variables.
The heat maps indicate the frequency (based on the number of regions) the projected change of a model variable is in full agreement with the desired change. The abbreviations of the scenarios are explained in Table 1.

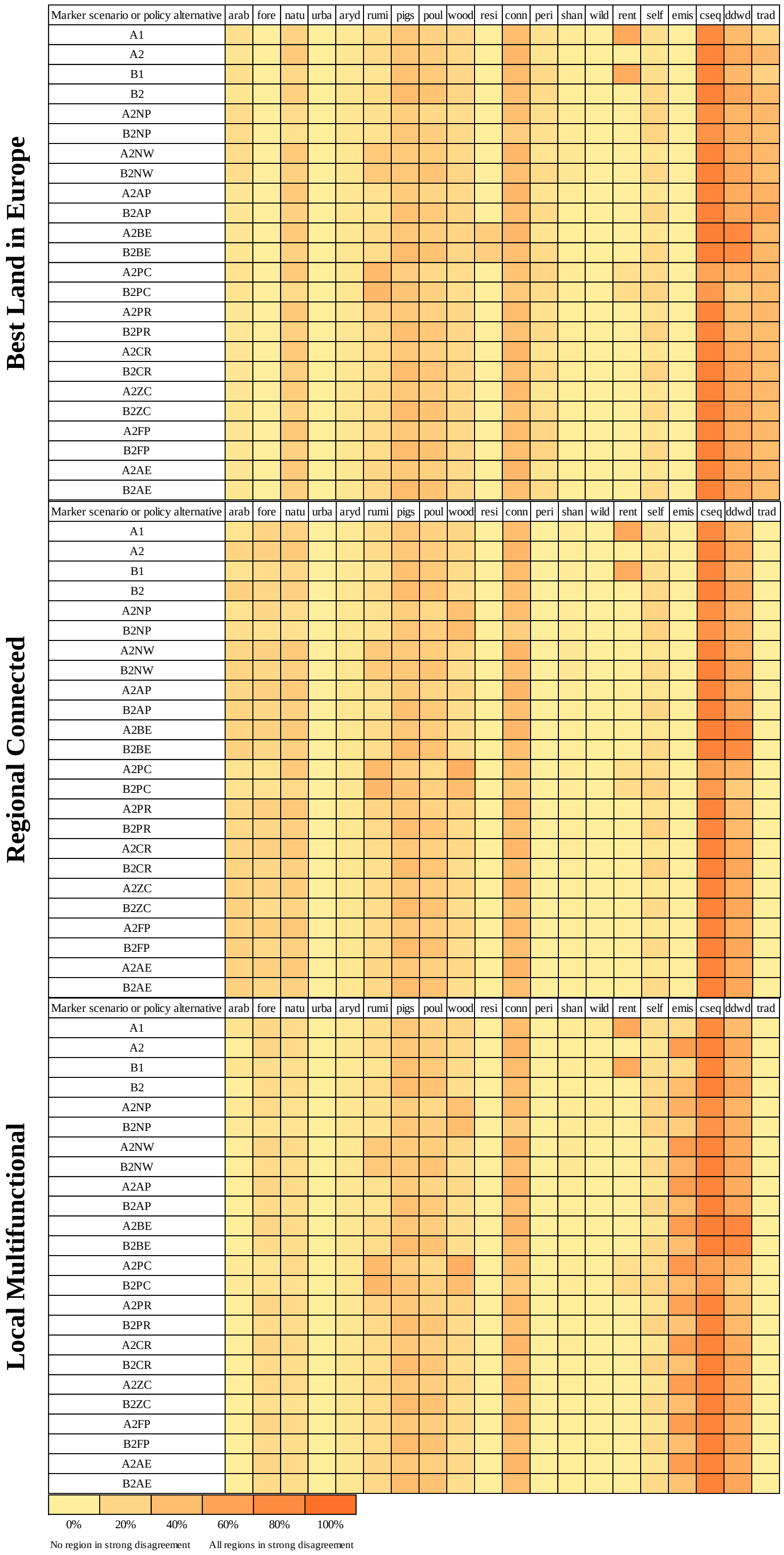

Figure S5: Heat maps for strong disagreement for model variables.
The heat maps indicate the frequency (based on the number of regions) the projected change of a model variable is in strong disagreement with the desired change. The abbreviations of the scenarios are explained in Table 1.

48

Best Land in Europe

Best Land in Europe	***Scenario***																							
Country / cluster	*A1*	*A2*	*B1*	*B2*	*A2NP*	*B2NP*	*A2NW*	*B2NW*	*A2AP*	*B2AP*	*A2BE*	*B2BE*	*A2PC*	*B2PC*	*A2PR*	*B2PR*	*A2CR*	*B2CR*	*A2ZC*	*B2ZC*	*A2FP*	*B2FP*	*A2AE*	*B2AE*
Austria																								
Belgium																								
Bulgaria																								
Cyprus																								
Czech Republic																								
Denmark																								
Estonia																								
Finland																								
France																								
Germany																								
Greece																								
Hungary																								
Ireland																								
Italy																								
Latvia																								
Lithuania																								
Luxembourg																								
Malta																								
Netherlands																								
Poland																								
Portugal																								
Romania																								
Slovakia																								
Slovenia																								
Spain																								
Sweden																								
United Kingdom																								
Peri-Urban																								
Rural																								
Deep Rural																								
North																								
Atlantic																								
Continental																								
Alpine																								
Mediterranean																								

Regional Connected

Regional Connected	***Scenario***																							
Country / cluster	*A1*	*A2*	*B1*	*B2*	*A2NP*	*B2NP*	*A2NW*	*B2NW*	*A2AP*	*B2AP*	*A2BE*	*B2BE*	*A2PC*	*B2PC*	*A2PR*	*B2PR*	*A2CR*	*B2CR*	*A2ZC*	*B2ZC*	*A2FP*	*B2FP*	*A2AE*	*B2AE*
Austria																								
Belgium																								
Bulgaria																								
Cyprus																								
Czech Republic																								
Denmark																								
Estonia																								
Finland																								
France																								
Germany																								
Greece																								
Hungary																								
Ireland																								
Italy																								
Latvia																								
Lithuania																								
Luxembourg																								
Malta																								
Netherlands																								
Poland																								
Portugal																								
Romania																								
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Spain																								
Sweden																								
United Kingdom																								
Peri-Urban																								
Rural																								
Deep Rural																								
North																								
Atlantic																								
Continental																								
Alpine																								
Mediterranean																								

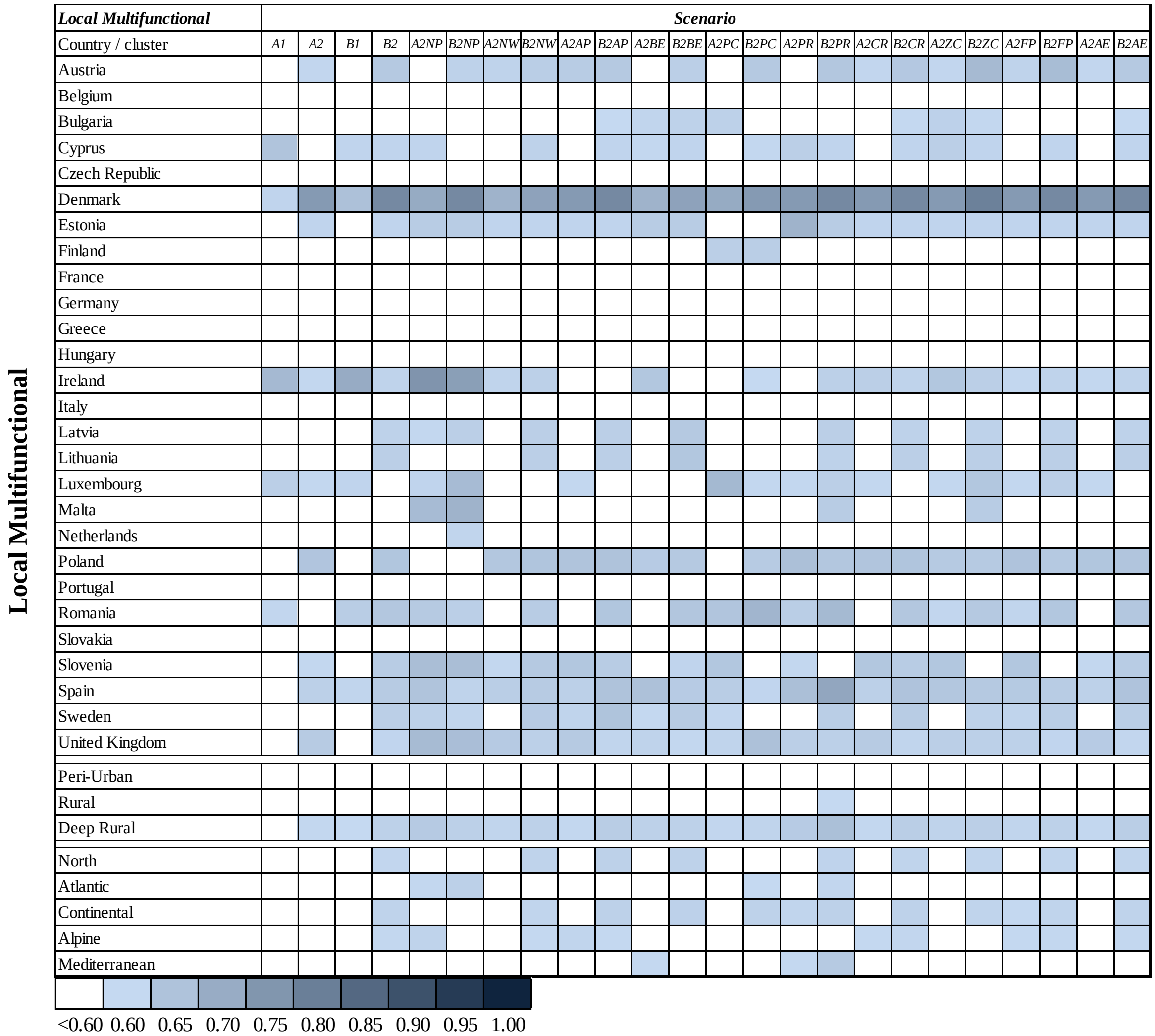

Figure S6: Heat maps for the level of agreement of scenarios.
The heat maps indicate the level of agreement of all scenarios with the visions for EU member states, rurality classes and main environmental zones. The abbreviations of the scenarios are explained in Table 1.

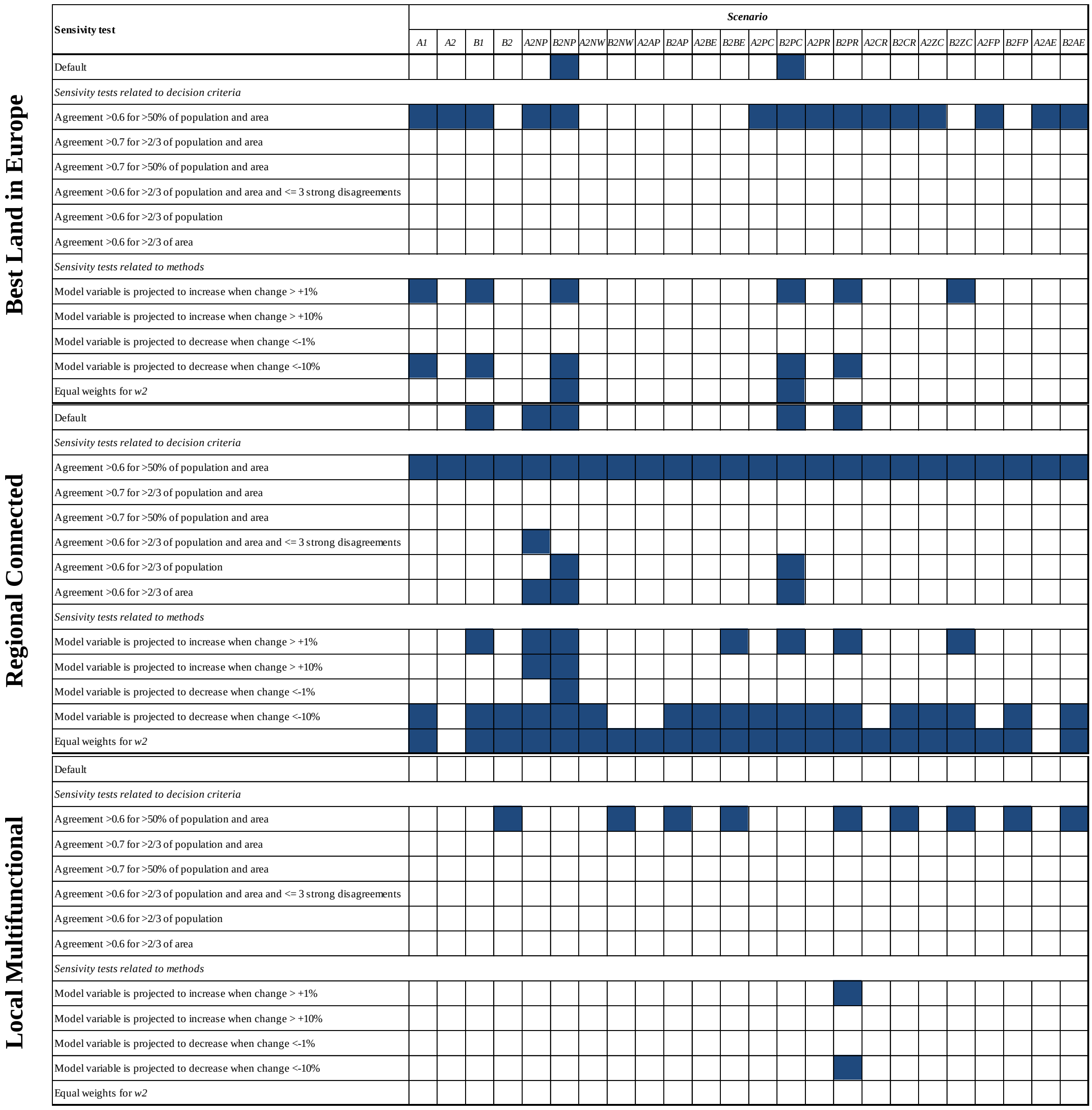

Figure S7: Sensitivity analysis.

Sensitivity analysis of how decision rules affect the identification of pathways to the visions. Pathways are indicated in blue. The abbreviations of the scenarios are explained in Table 1.

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