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Can we be certain about future land use change in Europe? A multi-scenario, integrated-assessment analysis

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ABSTRACT

The global land system is facing unprecedented pressures from growing human populations and climatic change. Understanding the effects these pressures may have is necessary to designing land management strategies that ensure food security, ecosystem service provision and successful climate mitigation and adaptation. However, the number of complex, interacting effects involved makes any complete understanding very difficult to achieve. Nevertheless, the recent development of integrated modelling frameworks allows for the exploration of the co-development of human and natural systems under scenarios of global change, potentially illuminating the main drivers and processes in future land system change. Here, we use one such integrated modelling framework (the CLIMSAVE Integrated Assessment Platform) to investigate the range of projected outcomes in the European land system across climatic and socio-economic scenarios for the 2050s. We find substantial consistency in locations and types of change even under the most divergent conditions, with results suggesting that climate change alone will lead to a contraction in the agricultural and forest area within Europe, particularly in southern Europe. This is partly offset by the introduction of socioeconomic changes that change both the demand for agricultural production, through changing food demand and net imports, and the efficiency of agricultural production. Simulated extensification and abandonment in the Mediterranean region is driven by future decreases in the relative profitability of the agricultural sector in southern Europe, owing to decreased productivity as a consequence of increased heat and drought stress and reduced irrigation water availability. The very low likelihood (<33% probability) that current land use proportions in many parts of Europe will remain unchanged suggests that future policy should seek to promote and support the multifunctional role of agriculture and forests in different European regions, rather than focusing on increased productivity as a route to agricultural and forestry viability.

1. Introduction

Humans have been changing the European landscape for millennia in response to their requirements for the many benefits or ecosystem services arising from the natural environment and its constituent resources. Developments in social systems, new technologies and crops, growing populations and economies have all had dramatic effects (Antrop, 2005; Fischer-Kowalski and Haberl, 2007). Climatic changes have also had substantial impacts, both on the landscape and on human societies, driving a complex pattern of inter-related environmental changes (Messerlia et al., 2000; Büntgen et al., 2011). Now, as the pace of socio-economic and climatic change continues to quicken, their consequences for the land system are commensurately greater and more uncertain. Climate change is likely to have impacts through changes in precipitation, temperature, CO_2 concentrations and sea level rise, affecting the suitability of land for different crops (Iglesias et al., 2012; Bindi and Olesen, 2011), tree species (Hanewinkel et al., 2013), habitats (e.g. Lehsten et al., 2015) and forms of management (e.g. irrigation - Garrote et al., 2015). Meanwhile, human activities will further modify the European landscape across scales, as populations, dietary preferences, trading patterns and management practices all change (Holman et al., 2008, 2016; Harrison et al., 2013; Rounsevell et al., 2006).

Previous research suggests that these non-climatic pressures may be more important drivers of land use change than climate change (Holman et al., 2005; Rounsevell and Reay, 2009). However, the diversity of social, economic, political and technical factors involved mean that future demands for living space and natural resources are hard to predict. This is exemplified by the breadth of potential socio-economic storylines used in impact assessments, from the global-to-regional Special Report on Emissions Scenarios (SRES; Nakicenovic and Swart, 2000) and Shared Socioeconomic Pathways (SSP; O'Neil et al., 2014) to the continental-to-national storylines developed by stakeholders (e.g. Kok et al., 2015; Metzger et al., 2010). Further uncertainty arises from differences between methods of analysis and modelling that emphasise

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distinct processes or sectors. These often give divergent projections even under identical climatic and socio-economic scenario conditions, suggesting that the identification and representation of major land change drivers requires significant improvement. In particular, the discrete sectoral nature of many models precludes consideration of the numerous cross-sectoral interactions that influence land use distributions (Harrison et al., 2016). Examples include changes in urban extent or coastal flood defence policy affecting agricultural land availability (Mokrech et al., 2008), and changes in population and water consumption affecting availability of water for irrigation (Henriques et al., 2008). Omitting such interactions can lead to substantial over- or under-estimation of climate impacts and direct and indirect consequences for land use (e.g. Reidsma et al., 2006; de Moel and Aerts, 2011; Di Lucia et al., 2012; Harrison et al., 2016).

One important outcome of uncertainty-focused model applications has been the identification of areas where high levels of uncertainty imply that land use is especially vulnerable to change. However, far less has been discovered about the areas where land use is robust to climatic and socio-economic pressures, and therefore the conditions which allow for the maintenance of food supplies, livelihoods, biodiversity and other ecosystem services. For this purpose, comprehensive scenarios and integrated modelling frameworks are particularly valuable because they allow for fuller, more realistic representations of the land system. Previous examples include studies focusing on future crop yields (Ewert et al., 2015; Wiebe et al., 2015), agricultural land use change (Piorra et al., 2009), broader land and/or energy usage (Verburg et al., 2008; Stürck et al., 2015; van Vuuren et al., 2016), inter-sectoral climate impacts (Fischer et al., 2005; Frieler et al., 2015), and policies for the sustainable development of land use systems (van Delden et al., 2010; Reidsma et al., 2011). Many of these studies involve integrated modelling of European land use; a particularly interesting case due to the research attention it has received in support of a coherent political system that attempts to influence land use outcomes across scales.

While Europe therefore provides a setting where advances in understanding of future land use change should be both possible and of practical value, this potential has not yet been fully realised. In particular, there has been a lack of assessment of the extent of certainty across land use categories under climatic and socio-economic changes acting directly and indirectly through representative cross-sectoral interactions. This paper addresses this gap using an integrated multi-sectoral modelling platform, the CLIMSAVE Integrated Assessment Platform (IAP), which incorporates a broader range of drivers and cross-sectoral processes than previous integrated models, and so allows for less strongly conditional projections of future land use change. We address two research questions:

1. Can highly uncertain futures lead to certain outcomes for European land use in the 2050s?
2. Where in Europe are the current distributions of land uses unlikely to change significantly in the medium term?

We use findings from the IAP to examine the conditions that generate projected stability, and their implications for political interventions intended to maintain land system functionality under global change.

2. Methods

2.1. The CLIMSAVE IA Platform

The CLIMSAVE[1] IA Platform (IAP) is an interactive, exploratory, web-based tool for simulating climate change impacts and vulnerabilities on a range of sectors (Harrison et al., 2013, 2015a). The Platform integrates a suite of models of urban development, water resources (Wimmer et al., 2015), coasts (Mokrech et al., 2015), agriculture and forests (Audsley et al., 2015), and biodiversity (Dunford et al., 2015a) to simulate the spatial effects of different climatic and socio-economic scenarios across Europe (Fig. 1). The IAP has been applied widely in climate change impact (Audsley et al., 2015; Holman et al., 2016; Wimmer et al., 2015; Harrison et al., 2015b; Mokrech et al., 2015; Harrison et al., 2016), adaptation (Dunford et al., 2015a) and vulnerability (Dunford et al., 2015b) assessments, in robust policy analysis (Jäger et al., 2015) and has been tested extensively through model sensitivity (Kebede et al., 2015) and uncertainty analyses (Dunford et al., 2014; Brown et al., 2015). The Platform operates at a spatial resolution of 10 arcmin × 10 arcmin (approximately 16 km × 16 km in Europe) grid cells, although multiple soil types are represented in each grid cell, and covers two thirty-year timeslices (2020s and 2050s).

2.2. Climate and socio-economic scenarios

2.2.1. Climate scenarios

The climate change scenarios within the IA Platform are based on combinations of the IPCC emissions scenarios (A1b, A2, B1 or B2), three climate sensitivities (low, medium or high) and five global climate models (GCMs). The five GCMs (MPEH5, CSMK3, HadGEM, GFCM21 and IPCM4) were chosen from the CMIP3 database using an objective method to represent as much uncertainty as possible due to between-GCM differences (see Dubrovsky et al., 2015 for further details). Projections of Europe-wide area-average temperature change across these climate models and scenarios range from 1.1 to 4.9 °C in winter and from 1.0 to 3.6 °C in summer in the 2050s. Projections for precipitation change range from increases of between 1.1 and 12.5% in winter and decreases of between 2.0 and 29.5% in summer. The pattern of temperature and precipitation changes differs according to the GCM (see Online Resource 2 of Harrison et al., 2015b). Although we acknowledge that there are more recent scenarios available than those in the IAP, the European area-average changes across these scenarios cover at least the 25th to 75th percentile range of the European changes in summer and winter precipitation and temperature change to 2065 for the CMIP5 global models for the RCP2.6 to RCP8.5 scenarios (Christensen et al., 2013).

2.2.2. Socio-economic scenarios

The IAP contains four European socio-economic scenarios that were developed by stakeholders in a series of professionally-facilitated participatory workshops (see Gramberger et al., 2015). In the first and second workshops, the objectively selected stakeholder group developed and iterated qualitative socio-economic stories and dynamics according to the two drivers that they considered most important and uncertain: "[*effective* vs *ineffective*] solutions by innovation" and "[*gradual* vs *roller-coaster*] economic development". This produced four scenarios which describe the contrasting evolution of a range of social, economic, cultural, institutional and political drivers in Europe (Kok et al., 2015):

- We Are the World – effective governments change the focus from GDP to welfare, which leads to a redistribution of wealth, and thus to less inequality and more (global) cooperation;
- Should I Stay or Should I Go – a failure to address economic crises leads to an increased gap between rich and poor, political instability and conflicts;
- Icarus – short-term policy planning and a stagnating economy lead to disintegration of social fabric and the shortage of goods and services;
- Riders on the Storm – strong economic recessions hit hard, but are successfully countered with renewables and green technologies. Europe is an important player in a turbulent world.

The qualitative stories and quantitative models were linked in a transparent and reproducible way using a "fuzzy set theory methodology" (Kok et al., 2015) in the first and (refined in) the second workshops

[1] CLimate change Integrated Methodology for cross-Sectoral Adaptation and Vulnerability in Europe