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Land use projections in China under global socioeconomic and emission scenarios: Utilizing a scenario-based land-use change assessment framework

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ABSTRACT

Land-use changes under the shared socioeconomic pathways (SSPs) and the representative concentration pathways (RCPs) have been analyzed globally, but how regional and national land use respond to the global mitigation policies is seldom explored, which poses difficulties in regional environmental adaptation and decision-making. China, as a major food consuming and biofuel production country, would suffer great uncertainties in future land-use dynamics under the global scenarios. Here, we present a scenario-based land-use change assessment framework, integrating Global Change Assessment Model and Future Land Use Simulation Model, to evaluate the potential land use projections of China from 2010 to 2100. Eight scenarios with different combinations of SSPs and radiative forcing targets of RCPs are designed, to analyze the impacts of the global socioeconomic and emission assumptions on regional mitigations and land-use changes. We recalibrated the historical land use data and urban dynamics of China to improve the consistency of modeling results with the actual regional changes. Meanwhile, differences in land use dynamics are demonstrated by spatial downscaling, which are jointly affected by the global assumptions and local driving factors, showing a fierce competition between the crop and forest. We find that the regional crop changes are sensitive to the socioeconomic dynamics as well as the bioenergy production, while different carbon regimes drive the forest changes in unexpected ways. Besides, overall heterogeneous landscape patterns and similar spatial suitability maps are found in distributions of land-use change between the emission and socioeconomic scenarios. The results indicate that this framework embedded with the consideration of anthropogenic managements as well as the detailed interactions of local environments provides an effective way to investigate regional land use response to a range of alternative future pathways.

1. Introduction

The importance of the land-use change for the global and regional environment has been recognized for its direct reflection of human activities as well as the close relationship with biodiversity, water resources, and the atmosphere (Foley et al., 2005; Brovkin and Boysen, 2013). It is estimated that greenhouse gas (GHG) emissions derived from land-use changes and agricultural activities account for a quarter of the global total emissions between 1990 and 2012, which mainly come from deforestation, animal feeding, fertilizer use, and land-use management (Tubiello et al., 2015). In China, land-use change has contributed to 15% of the total carbon emission from 1990 to 2010, resulting from different land-use change factors of urbanization, cultivation, and various land-use conversions (Lai et al., 2016). Therefore, future land-use dynamics play a crucial role in the process of achieving the global mitigation target, resulting in tremendous pressures on more reasonable land use management as well as effective global policies and technologies, which are associated with the regional land-use changes through globalized trade and food markets (Verburg et al., 2008; Popp et al., 2017).

With the rapid economic development of China in recent twenty years, intensified urban expansion has encroached on a large proportion of croplands, while the deforestation in the middle and western China has been slightly relieved as a consequence of the ecological defarming policy (Liu et al., 2010; Kuang et al., 2016). Facing to a diverse range of alternative futures, China will experience significant

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land-use uncertainties which are strongly dependent on population dynamics, demands of food yields and biofuels under the global mitigation target. To better informed the potential impacts of new policies and technologies on the environment especially for land use, Integrated Assessment Models (IAMs) such as the Integrated Model to Assess the Global Environment (IMAGE) (IMAGE Team, 2001; Strengers et al., 2004) and the Global Change Assessment Model (GCAM) (Kim et al., 2006; Clarke et al., 2007) have been developed by linking the land use system and the climate model to global assumptions and policies. With IAMs, a series of global-scale scenarios are built up, the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES) (Nakicenovic et al., 2000) and the Representative Concentration Pathways (RCPs) (Moss et al., 2010; Van Vuuren et al., 2011) for example, to assess future land use and emission trajectories under diverse climate mitigation measures.

Regional landscape patterns produced by spatial explicit land use models illustrate local interactions among environmental processes under human intervention which has not yet been comprehensively understood (Meyfroidt et al., 2013; Newbold et al., 2015). Systematic analyses are required to explore land use response to multiple global measures not only in quantity but also in geospatial variations (Prestele et al., 2016). Thus, frameworks that combine global scenarios from IAMs with spatial explicit land-use models have emerged (Table 1). But land use projections from previous studies are most processed in coarse spatial resolutions (0.5°*0.5°, 0.25°*0.25°) which neglect the critical distributional consequences at regional and local level, resulting in the obscuring of significant effects on local land use dynamics caused by small-scale environmental variables such as soil, topography, and local climate (Thomson et al., 2014; West et al., 2014; Barbier, 2014). Although there are frameworks that achieve land use in fine resolutions, most of them are based on scenario data from the existing datasets or pre-calculated results other than the actual model. These rarely have access to the foundational data and parameters and thus users are not allowed to design and accomplish simulation for the relevant policy factors, which results in constrained capabilities to make scenario and policy assessments (Van Delden et al., 2010; Sleeter et al., 2012). For instance, a Future Land Use Simulation (FLUS) (Li et al., 2017; Liu et al. 2017) model applying the existing SRES scenario data from IMAGE generates a series of scenario-induced land use products but is unable to provide comparisons among user-specified socioeconomic factor or mitigation policies.

With the prosperous of global scenario works, new sets of socioeconomic scenarios as well as emission scenarios, the Shared Socioeconomic Pathways (SSPs) (O'Neill, et al. 2014; O'Neill et al., 2017) and RCPs, are proposed to describe potential pathways for different emission and socioeconomic conditions and to evaluate societal capabilities to deal with mitigation and adaptation challenges (O'Neill et al., 2014; Van Vuuren et al., 2014). Scenario analysis, therefore, can be utilized to quantitatively explore land use futures induced by the interactions of various driving forces (Alcamo, 2001). In SSPs, population and GDP of China are predicted to have distinctive pathways with those of global total especially for population, among which the peak amount arrives over 1.4 billion around 2030 and keep decreasing thereafter for China in SSP3 (KC and Lutz, 2017), resulting in complicated dynamics of demands for agricultural lands (Popp et al., 2017). While mitigation policy of bioenergy deployment for energy yields and carbon storage drives an increasing need for the total crop demand which can be suppressed by application of the Universal Carbon Tax (UCT) policy with pricing terrestrial carbon emissions (Wise et al., 2009; Reilly et al., 2012; Humpenöder et al., 2015). Thus, land use dynamics differ greatly under different combination of socioeconomic as well as emission mitigation pathways, which is crucial in process of land use decision making and should be explored in detail. Similar research has been figured out for both Europe and the US to assess implications of multiple climate scenarios for land use (Verburg et al., 2006; Rounsevell et al., 2006; Sohl et al., 2012; Thomson et al., 2014).

Table 1
Selected existing scenario-based land-use change assessment research (sort by spatial resolution).

Research	land use types	Study area	Scenarios	Method/model	Temporal resolution	Spatial resolution
Hurtt et al. (2011)	Crop, pasture, primary, secondary, wood, harvest, biomass	Global	IPCC RCPs	GCAM, Global Land-use Model (GLM)	1500–2100, 5-year	0.5°*0.5°
Reilly et al. (2012)	Crop, grassland, pasture, Biomass, carbon emission	Global	Global energy and land use scenarios	MIT Emissions Predictions and Policy Analysis model, Terrestrial Ecosystem Model	2000–2100, 5-year	0.5°*0.5°
Popp et al. (2014)	Cropland, pasture, forest and other lands	Global	RCP2.6, terrestrial carbon policy	Model of Agricultural Production and its Impacts on the Environment (MAgPIE)	1995–2100, 5-year	0.5°*0.5°
Le Page et al. (2016)	Forest, shrub, grass, crops, urban, sparse	Global	Reference and RCP 4.5	GCAM, rule-based downscaling method	2005–2100, 5-year	0.25°*0.25°
West et al. (2014)	MODIS plant functional type (PFT)	Global	Global emission mitigation scenarios	GCAM, kernel density and distance method	2010–2100, 5-year	0.05°*0.05°
Sherba et al. (2015)	Urban, forest, wetland, grass/shrub, cropland	Pacific Northwest, US	IPCC RCPs	State-and-transition simulation model (STSM)	2005–2100, 5-year	10 km*10 km
Sun et al. (2011)	10 land use types	China	IPCC SRES	Dyna-CLUE	2000–2099	2 km*2 km
Verburg et al. (2006)	Agriculture, urban	Europe	IPCC SRES	IMAGE, CLUE-s	2000–2030, 2-year	1 km*1 km
Li et al. (2016)	8 land use classes	Global	IPCC RCPs	Cellular automata model	2010–2100, 5-year	1 km*1 km
Li et al. (2017)	Forest, grassland, water, farmland, urban, barren	Global	IPCC SRES	IMAGE, FLUS	2010–2100, 5-year	1 km*1 km
Rounsevell et al. (2006)	Urban, cropland, grassland, forest	EU15, Norway and Switzerland	IPCC SRES	IMAGE2.2, spatial allocation rules	2020,2050,and 2080	250 m*250 m
Sleeter et al. (2012)	16 land use classes	US	IPCC SRES	IMAGE2.2, FORE-SCE model	2000–2100, 5-year	250 m*250 m
Sohl et al. (2012, 2014)	14 land use classes	The Great Plains, US	IPCC SRES	IMAGE2.2, FORE-SCE model	1992–2100, yearly	250 m*250 m