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The Uncertain Future of Biofuels in China and Impacts on the Food-Land-Water Nexus: A Multiscale Analysis

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Abstract

With biofuel's co-benefits of relieving dependence on fossil fuel and reducing greenhouse gas emissions, it would be increasingly important to expand the consumption of biofuel in order to achieve sustainable development. By far, China has set up ambitious targets on improving its biofuel usage. However, considering future socio-economic development, impacts of biofuel expansion on China's crop production and input use remains uncertain. To address this question with an integrated analytical framework, we developed the Simplified International Model of agricultural Prices, Land use and the Environment: Gridded version for China (SIMPLE-G-China), a partial equilibrium model following the global-local-global approach, to research the impact of biofuel demand on China's crop production and inputs use. Based on simulations of four policy scenarios projecting to 2040, it is found that the increased demand of crop as food sector inputs and technology improvement are key factors for future crop production and input use in China, while impacts from biofuel expansion would be moderate. Also, the model shows the spatial variance of impacts on crop production, land and water use. Findings from this study would provide insights for government to formulate more efficient biofuel policies, improve policy assessment, and facilitate stakeholder's decision making.

1. Introduction

To achieve a more sustainable future, it would be increasingly important to explore the overall impacts of biofuel as an alternative energy choice. Comparing with fossil fuel, biofuel would not only provide a renewable source of energy and increase energy self-sufficiency, but also have co-benefits such as reducing air pollutants and green-house gas emissions, increasing agricultural returns and promoting rural development (Balat & Balat, 2009). However, the expansion of biofuel production (especially the first-generation biofuel) would also cause competitions with food production on major

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agricultural inputs such as land and water, and those impacts would be further transmitted to food supply insufficiency, food price raise and malnutrition (Pimentel et al., 2008). Those double-edged effects of biofuel suggest that large-scale program of biofuel production requires comprehensive assessment on its impacts on food-land-water nexus.

Comparing with other countries with active biofuel promoting policies and programs such as the United States, Brazil and European Union, the impacts of biofuel expansion in China would be associated with more uncertainty. On one side, with the world's top population to feed, China already faces a severe challenge of maintaining sufficient food supply with both population growth and consumption raises due to socio-economic development. Then a large-scale biofuel expansion program may further exacerbate this challenge. One the other side, the socio-economic development in China would also increase the demand of energy. Given the current scarcity of domestic fossil fuel supply, China is expected to depend more on biofuel as an alternative and renewable source to satisfy the increased energy demand (Yang et al., 2009). Besides drivers from future food and energy demand sides, achieving energy and climate associated sustainable development goals also requires the transition from fossil fuels to renewable fuels in energy structure, which would become a third factor influencing future biofuel policies (IEA, 2019). Until recently, China has set up ambitious targets on improving its biofuel usage. In 2016, the National Energy Administration of China announced the 13th five-year-plan on Bioenergy development, which aims at producing four million-tonne bio-ethanol and two million-tonne of bio-diesel by 2020 (IEA, 2017). In 2017, China further announced a mandatory policy on promoting E10 gasoline (Gasoline with 10% as ethanol) use for the whole country (Li et al., 2017). However, the picture for strong growth in biofuel demand becomes gloomy as low oil prices hit demand for ethanol, corn stocks sharply decline, and government support for ethanol wanes. It has been reported that China has suspended the E10 gasoline policy (Gu et al., 2020), and would only achieve ethanol rate of 3 to 3.5 percent by 2020 (Kim, 2019). Given those uncertainties ahead, will China continue to promote biofuel use in its fourteenth "five-year plan" (2021 -2025) or even longer term? If so, what would be the implications for food security, environment, and ecosystem?

Addressing these questions will require an integrated analytical framework. By far, biofuel production have been found to result in crop production and price variance (e.g.

Al-Mulali, 2015), land use change towards energy crops (e.g. Weng et al., 2019). To plant energy crop on marginal land could mitigate these negative effects, but it would require additonal water use for irrigation (e.g. Fu et al., 2019) and higher nitrogen fertilizer application (e.g. Chen et al., 2017). However, the majority of studies focuses on only one certain aspect of impacts, rather than providing comprehensive assessment of biofuel expansion on the nexus of food, energy, land, and water. Furthermore, a gap still exists between shock on macro level and response on local level. Although many aspects of the impacts would be spatially heterogenous, most of previous studies researched biofuel production's effect on regional, provincial or county level (Jiang et al., 2017; Qiu et al., 2010; Shu et al., 2015). As the result, they cannot reflect the heterogeneity in local response of biofuel expansion. With the help of GIS-based data and technology, an increasing number of studies have been conducted on the energy crops production and potentials in China at the grid-cell level (Nie et al., 2019; Wang et al., 2013). However, these studies emphasize more on the agricultural or bio-energy aspects of crop production itself, but do not incorporation the influence from supply-demand relationship for both crops and other commodities.

Existing literatures and their limitations suggest that in order to fully understand the overall impacts of biofuel expansion, it is necessary to take a multi-scale approach: the analysis should be conducted under the scenario of national and global population and socioeconomic growth, solved on local level to capture spatial heterogeneity and provide spatial-specific estimation on food-land-water nexus. Also, it should incorporate interactions with the demand and supply of non-crop sectors. The present paper provides an attempt to research the overall impacts of biofuel expansion for China. In this study, we developed a multi-scale model to address the demand and supply of food and non-food commodities and also inputs for crop production on spatial level for China. Under the model's framework, we simulated the global commodity consumption and production projected to 2040 and analyzed impacts of different biofuel promoting policies on China's food-land-water nexus. Findings from this study would provide insights for government to formulate more efficient biofuel policies, improve policy assessment, and facilitate stakeholder's decision making.

The rest sections of this paper are organized in the following way: section 2 provides a description of the model established, including the modelling framework, equilibrium conditions and structure of database. Also, it introduces scenarios of social-economic development and biofuel expansion for simulation. Section 3 reports and discusses results obtained from simulation. Finally, section 4 concludes major findings and implications from the paper.

2. Method

2.1 SIMPLE-G-China model

The Simplified International Model of agricultural Prices, Land use and the Environment: Gridded version for China (SIMPLE-G-China) model is a partial equilibrium model with GEMPACK software, which aims at projecting the local response of crop production and input use from global level shocks on demand, technology and policy. The SIMPLE-G-China model is developed based on the original theoretical paper about the SIMPLE framework (Thomas W. Hertel, 2011), the SIMPLE model (Baldos & Hertel, 2012) and global gridded SIMPLE model (SIMPLE-G-Global) (Liu et al., 2017). It inherits the basic framework and structure of SIMPLE and SIMPLE-G-Global model but has following improvements. On spatial aspect, in SIMPLE model the world is grouped into five demand regions and seven supply regions. While the SIMPLE-G-Global has 16 regions on demand side, it separates the whole world into 39,168 30 arcmin-squared grids to capture the spatial pattern of supply. In SIMPLE-G-China, we keep the demand side and all non-China regions on the supply side as 15 aggregated regions, but separate China into 41,911 five arcmin-squared grids, in order to provide estimation on finer spatial scale. On temporal aspect, while existing SIMPLE and SIMPLE-G-Global model use 2001 or 2006 as base year, in SIMPLE-G-China model, we updated the base year of database to 2017, in order to better reflect concurrent status. Those improvements make it a unique tool for researching the shock and response on China's food-land-water system with fine spatial resolution.

The SIMPLE-G-China model is solved with a global-local-global (GLG) approach, as is shown on Figure 1. On demand side, the model takes exogenous changes on population, per capita income, technological change and biofuel demand from regional level, calculates consumption of three commodities in food categories (crop, livestock and processed) and one non-food commodities. Since crop is both consumed directly and also purchased as input for livestock and processed food production, these three commodities together determine the demand for crops. On supply side, five inputs (fertilizer, land, water, irrigation equipment and other inputs) are nested with CES functions to form crop production, and the model solves cost minimization problem for crop producers to determine the input level change on grids for China and on regions for rest of world. The grid level production and inputs are further aggregated back to regional level, to determine the price on input and output markets with demand side. In this study, population growth, income rise, production technology improvement and crop use for biofuel are assigned according to simulation scenarios, while the demand for food commodities and crop production inputs and their price are endogenous and solved from the model.

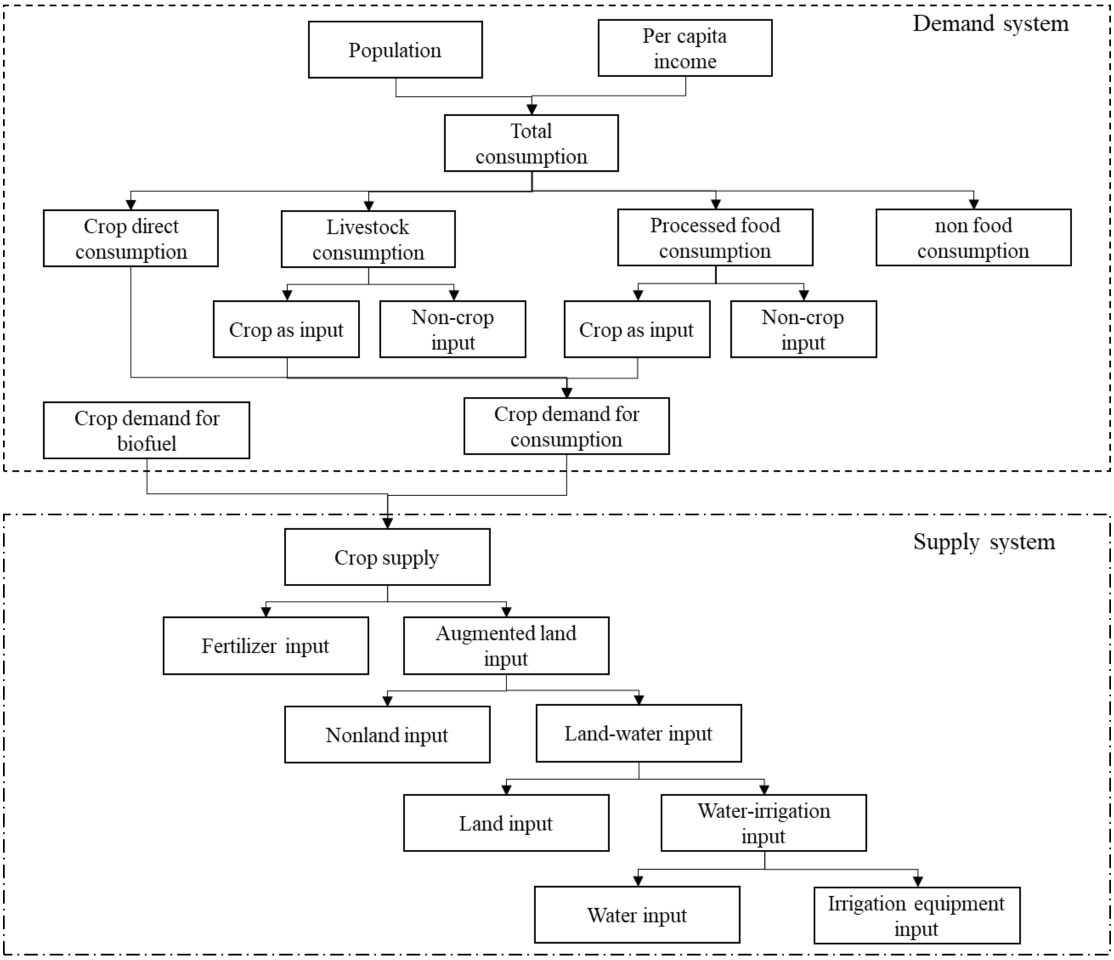

Figure 1 Structure of SIMPLE-G-China model

To construct the database for year 2017, we obtained population, per capita income (represented by per capita GDP) and total consumption data from World bank database, and cropland, crop output and crop price data from FAOSTAT database. Since SIMPLE-G-China is an all-crop model, we further calculated a price-based weight for each crop, converted them to be equivalent to rice and aggregated for the total crop output. For China, we further calculated the crop production, input use and cost of each input based on the grid-level data from MODIS (for cropland), MICRA (for output and water use) and EarthStat (For nitrogen fertilizer use), and adjust those grid-cell level data for year 2017 with the aggregated national or provincial level data from China Statistical Yearbook or the compilation of China's agricultural input and output. The data of crop used as inputs for livestock and processed food production are obtained from GTAP V10 database. Finally, we calculated the change of crop used for biofuel from the projected growth of biofuel use for transportation (representing the use of crop with first-generation technology) between 2017 and 2040 from World Energy Outlook.

2.2 Policy scenarios

In order to model impacts of biofuel expansion for China, we designed four simulation scenarios projecting from 2017 to 2040 that include two aspects of effects: (1) uniform projection on population, income, technology for the whole world from Hertel et al., (2014), and crop demand for biofuel for non-China regions; (2) specific projection on crop demand for biofuel for China only. Projections of China's biofuel expansion are based on three policy scenarios from the World Energy Outlook: the current policies scenario, or business as usual (BAU) scenario, the stated policies (STA) scenario, and the sustainable development (SUS) scenario. In the BAU scenario, each country is assumed to keep the current energy use path. In the STA scenario, energy use path is projected according to policies that have been announced by far. While the SUS scenario is designed to achieve the climate control goal proposed in the Paris Agreement and also promotes access to energy and air pollution control (IEA, 2019). As discussed above, China as suspended its E10 gasoline policy and the future of biofuel relevant plans and policies are also gloomy. Thus, we further design a fourth scenario assuming that biofuel use in China would be still at its 2017 level (STL) as a pessimistic projection. The projected changes from these scenarios are shown in table 1 below.

Table 1 Percentage change of exogenous variables

Region	Population	Per capita income	TFP (Crop)	TFP (Livestock)	TFP (Processed food)	Biofuel (BAU)	Biofuel (STA)	Biofuel (SUS)	Biofuel (STL)
Eastern Europe	-7.96	190.77	20.94	26.87	22.60	0.00	--	--	--
North Africa	26.29	120.12	55.57	-6.68	22.60	0.00	--	--	--
Sub Saharan Africa	74.10	135.80	19.57	10.12	22.60	0.00	--	--	--
South America	16.60	80.87	48.70	82.09	22.60	94.74	--	--	--

Australia/New Zealand	26.87	44.72	38.94	10.12	22.60	312.50	--	--	--
European Union	2.56	35.82	61.28	12.16	22.60	80.00	--	--	--
South Asia	20.94	205.14	30.38	47.69	22.60	300.00	--	--	--
Central America	21.21	72.54	30.67	82.09	22.60	94.74	--	--	--
Southern Africa	15.80	81.27	47.03	10.12	22.60	0.00	--	--	--
Southeast Asia	19.84	129.10	44.72	71.77	22.60	175.00	--	--	--
Canada	16.33	26.00	45.70	10.12	22.60	67.50	--	--	--
USA	16.33	26.00	45.70	10.12	22.60	71.05	--	--	--
China	2.33	273.77	58.05	71.77	22.60	700.00	1050.00	1550.00	0.00
Middle East	31.87	26.00	38.31	-5.59	22.60	0.00	--	--	--
Japan/Korea	-4.50	56.27	64.22	10.12	22.60	0.00	--	--	--
Central Asia	24.58	200.49	20.94	26.87	22.60	0.00	--	--	--

2.3 Model validation and simulation

Before projecting future crop production and input use, SIMPLE-G-China model was validated by hindcasting from base year 2017 to 2000. We firstly calculated the change of population and per capita GDP from World bank database and TFP from Hertel et al., (2014) during this period, and assumed crop demands for biofuel use in 2000 are zero. Then we ran the SIMPLE-G-China model and compared results on regional cropland and crop output with the real-world data from FAOSTAT in 2000. Figure 2 shows the comparison between estimated and real data on regional level. For aggregated world level, the model underestimated crop output by 8.2% and cropland use by 7.6%. While for region-specific level, the model estimation captures the general pattern for global regions, but the magnitude of error differ across regions. Finally, for China, the error on crop output and cropland use are -9.8% for crop output and -6.6% respectively. So the validation indicates that the SIMPLE-G-China model can provide relatively accurate projections with exogenous shocks. Then we ran the model with shocks from the four policy scenarios above and projected the response in crop production and input use, as the percentage change of variables from the 2017 baseline level.

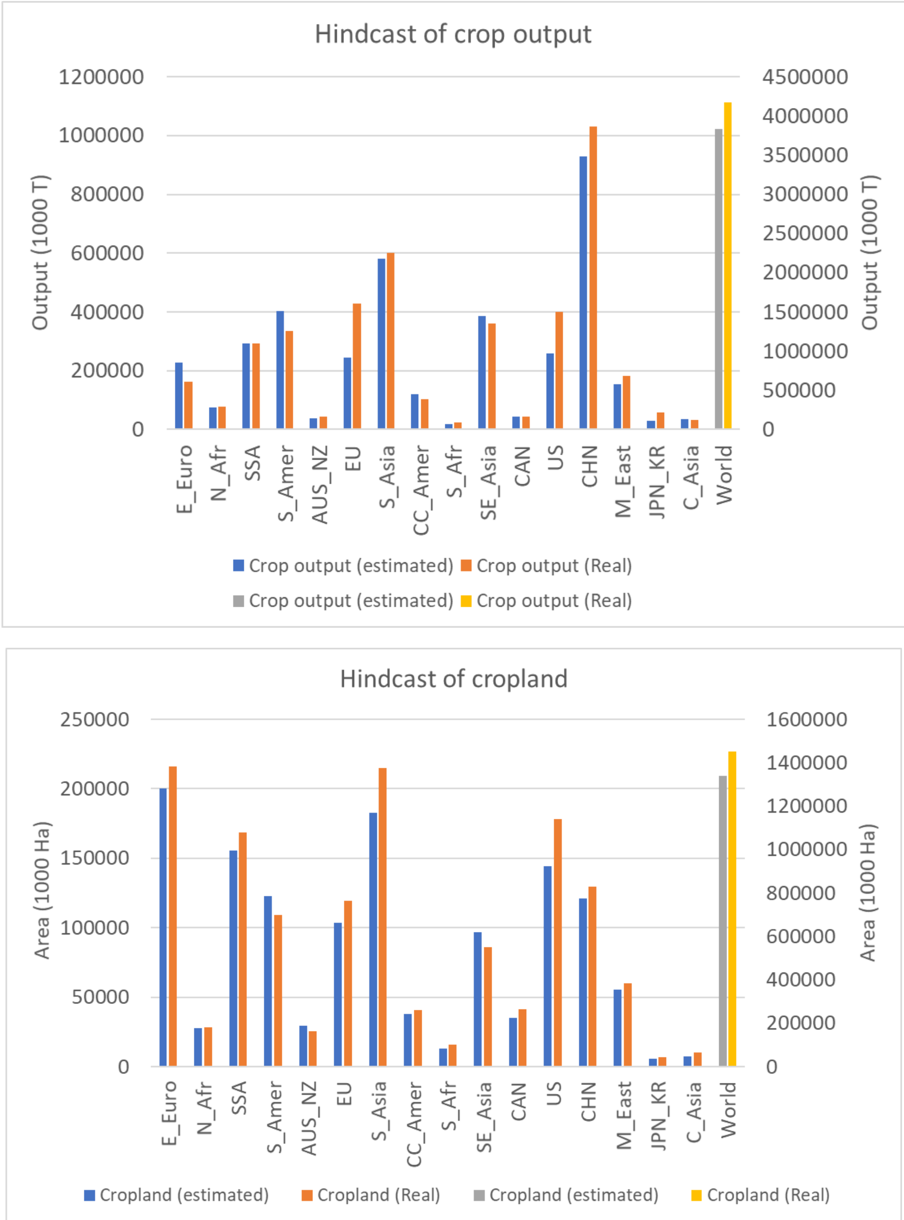

Figure 2 Hindcast validation of SIMPLE-G-China model

3. Results and discussion

Figure 3 shows the projected change of crop output and input requirement for land and water, under all four scenarios from 2017 to 2040. As is shown in figure 3, the model estimates national crop output would increase by 50%, however, inputs use for both land and water would decrease slightly by 2-5%. The reason for both increased crop output and decreased input use is as follows: when China is expected to have small percentage change of population but large change of income, its consumption structure changes greatly, resulting in decreased demand of crop for direct consumption but increased demand of crop as inputs for livestock or processed foods sector, which becomes the major driver of crop output change. On supply side, the increase of crop output is offset by increased TFP on crop production, so all crop inputs would decrease slightly. So these results indicates that technology improvement would be the key factor to achieve sustainable agriculture. Also, from figure 3 it is found that the impacts of crop demand for biofuel (difference between scenarios) are relatively small (1-2%) comparing with impacts of income and technology change, which indicates that biofuel expansion may not be a top threat of food security in the future, if we also take general socio-economic development into consideration.

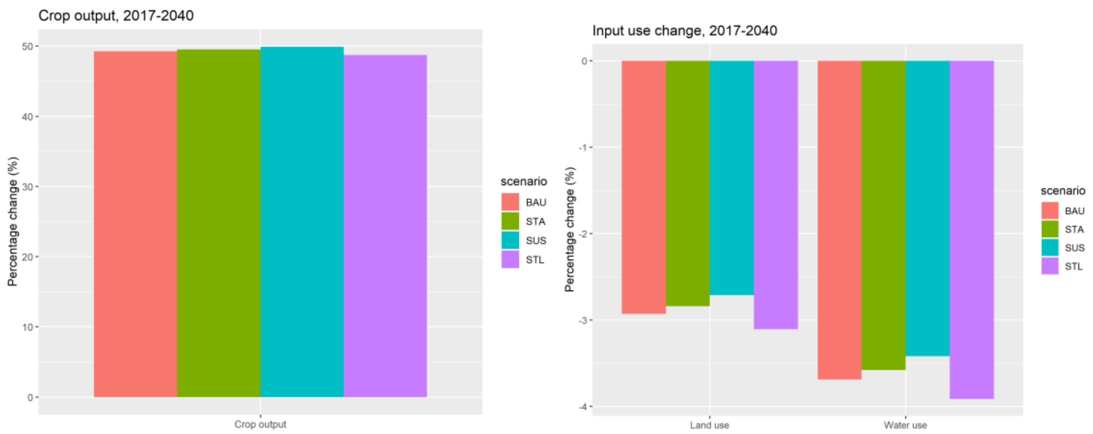

Figure 3 Crop output and input use change

Besides the aggregated projection on national level, SIMPLE-G-China model also provides projection on grid-cell level. Figure 4 shows the result of crop output change and input use on spatial level, for both irrigated and rainfed cropland. According to figure 4, crop production on both irrigated and rainfed land, shows spatial variance. On irrigated cropland, impact of exogenous shocks would be potentially larger in north and northeast China, while on rainfed cropland, spatial variance of impact still exists, but is milder. The input use pattern of land and water use are similar with crop output on irrigated land, but the spatial variance are much smaller. Results here indicates that when facing the socio-economic shock on national level, the local response on crop production and input use are not uniform but would vary due to the spatial heterogeneity of crop production. So results here imply the importance of fine scale analysis for policy making and impact assessment.

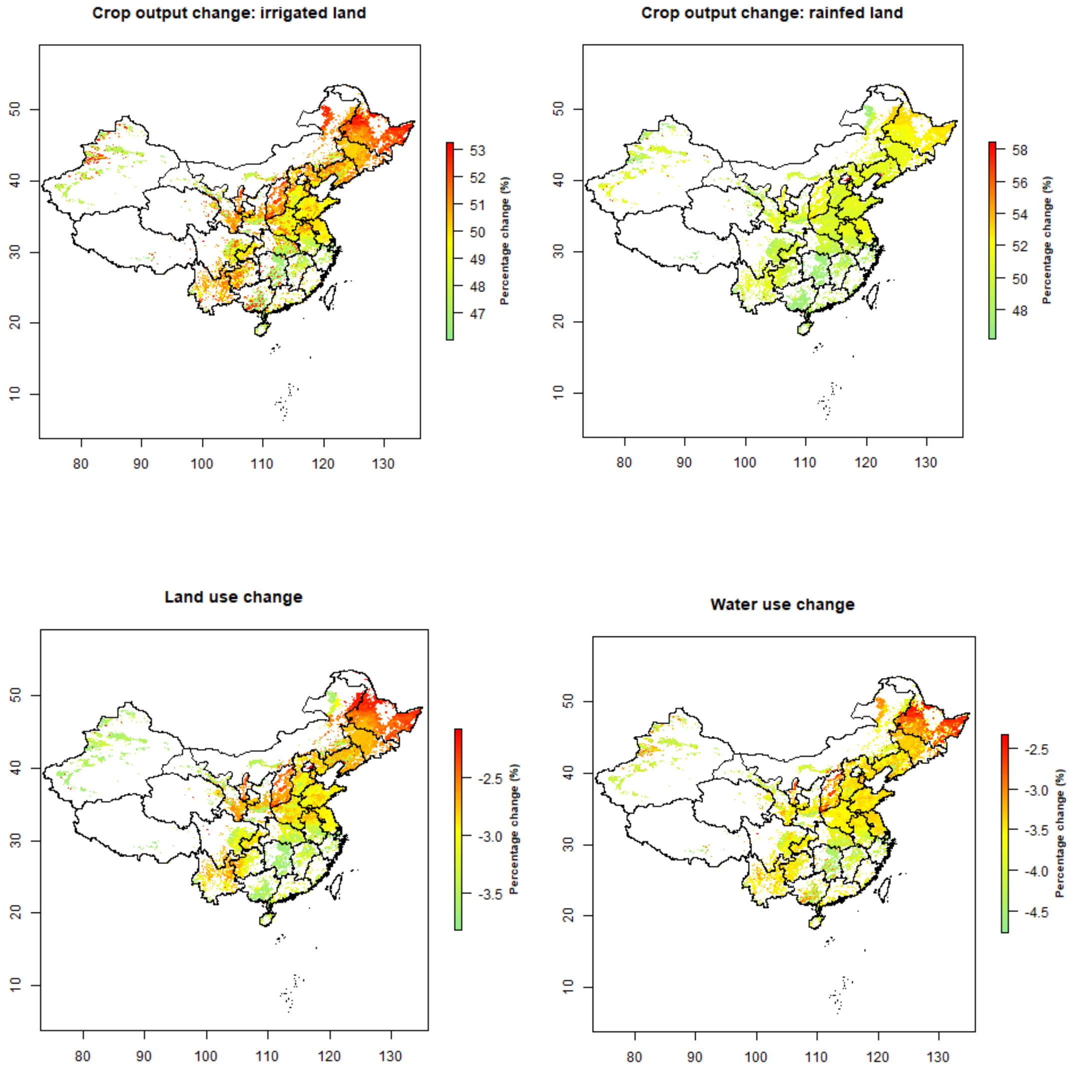

Figure 4 Crop output and input change on spatial level (BAU)

Since results shown on figure 4 incorporate two aspects of impact: general socio-economic growth towards 2040 and specific crop demand for biofuel production, we further separated them and evaluated the impact from biofuel demand only, using the difference of input change between the scenarios with most and least biofuel expansion, SUS and STL. Figure 5 shows the difference of cropland use change and water use between SUS and STL Although the difference of input use change also shows spatial variance, their impacts are much smaller comparing with the lower panel of figure 4, which indicates that impacts from uncertainties of biofuel expansion would be only on moderate degree.

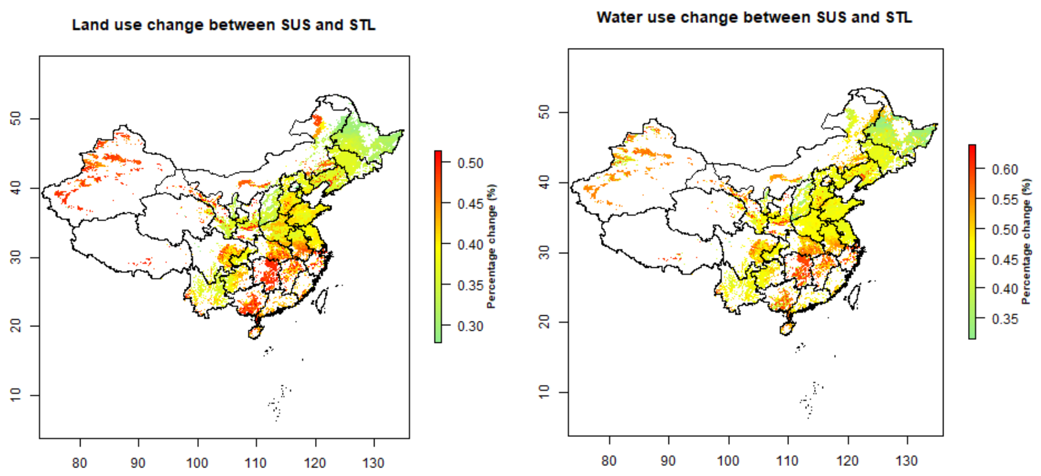

Figure 5 Difference of land and water use between SUS and STL

Finally, several limitations exist in the present paper. Firstly, although in SIMPLE-G-China model the crop output and input use data are collected on grid cell level, the shock of TFP change and parameters in production function are still uniform on national level, which may expain the relatively small degree of spatial variance. We plan to overcome this limitation by calibrating parameters on a finer resolution, from national level to province, city or even grid cell level, based on the availability of data. Secondly, since the developing level and natural endowment would differ greatly all over China, it is meaningful to further add region-specific constricts on water and cropland, which are not included in SIMPLE-G-China model by far. Finally, except for the national planning of biofuel expansion, each province or sub-national region may also have its own planning on biofuel production, so the scenarios can be further modified to incorporate spatial-specific policies.

4. Conclusion

Biofuel is a promising energy source for sustainable development for China, however, its impacts on crop production and input use remain insufficiently researched. By conducting multi-scale projections with SIMPLE-G-China model, it is found that in the future, increase in crop production would be mainly driven by higher demand for livestock and processed food due to income growth and consumption structure change, while technology improvement would be key factor for sustainable agricultural production. Comparing with the general socio-economic growth, the crop demand for biofuel would only have moderate impacts on crop production and input use, and is not the major concern of food security. Furthermore, the multi-scale research approach shows the spatial heterogeneity of impacts on the food-land-water system, which would contribute to region-specific policy design, and indicate the importance of fine scale analysis.

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