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Alternative spatial allocation of suitable land for biofuel production in China

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ABSTRACT

How to select locations for biofuel production is still a critical consideration for balance of crop and biofuel productions as well as of energy consumption and environmental conservation. Biofuels are widely produced all over the world, but this practice in China is still at the initial stage. Based on China's current stage on food security and changing biofuel demands, this paper selected agro-environmental and socio-economic factors of biofuel production, and simulated and spatially allocated areas suited for biofuel production under the two scenarios of planning-oriented scenario (PoS) and biofuel-oriented scenario (BoS) by the target year 2020. It also estimated biofuel production potentials and zones across China's provinces. The results show that land suited for biofuel production is primarily located in Northwestern, Northern, Northeastern, Central and Southwestern China, with relatively good agro-environmental conditions and medium population density, but also lower competition with crop production, aiming at facilitating governmental policy-making and multi-purpose allocation of land.

1. Introduction

Fossil fuels combustion to produce energy poses one of the major environmental concerns due to global greenhouse gases (GHG) emissions causing global warming. Bioefuel production can be alternative to fossil fuels (Marisson and Larson, 1995). Currently, European, Latin American countries, USA, but also some developing countries have been involved in a large-scale production of biofuels (Liu et al., 2013). The rapid increase of biofuel production and demand alters land use dynamics (Rathmann et al., 2010) and forces additional competition with existing land uses, such as crop, fodder and livestock production (Bai et al., 2012). Thus, land transformation and competition of land uses accelerate a debate about alternatives to conversion of land for food and/or biofuel production (Lange, 2011; Mosnier et al., 2013), with possible consequences for food security and environmental sustainability (Bai et al., 2012; Ravindranath et al., 2011). Thus, it is a challenging task to understand, how the human dimension, both social and developmental aspects are considered regarding biofuel and food security concerns and imbedded into energy production. One way to resolve the competition between land uses at national and regional level, is to perform spatially explicit land allocation from a finite number of candidate parcels or a set of parcels, to best meet the needs for the specific land use objective (Benabdallah and Wright, 1992).

In general, the increase of biofuel production can be achieved by the increase of production intensity per parcel or by cropland expansion. Often land with good agro-environmental endowment is prone for increase of yields and better incomes. Under high biofuel prices and demand, this may on the one hand increase productivity per parcel, on the other hand, biofuel production expansion at the expense of other land uses, abandoned lands and pristine areas (Langeveld et al., 2014). Not a surprise, biofuel production first takes place at the expense of already cultivated, well drained and highly productive farmland primarily due to better production conditions and accessibility compared to other land cover and land use types (Balogun and Salami, 2016). But environmental conditions are still the majority of sustainability criteria for biofuels (Markevičius et al., 2010).

One of the important tasks is to spatially allocate land suited for biofuel production. Geographic Information System (GIS) is a widely used tool to allocate lands suited for biofuel analysis in a spatial manner (Goor et al., 2003). GIS also facilitates the multi-criteria decision analysis (MCDA) to allocate suitable areas (Greco et al., 2016), and it is used to input the geo-referenced data, stimulate their spatial distributions and changes, commonly such as road layouts, existing land uses, population densities, etc. (Martini et al., 2015; Schneider et al., 2001), and then calibrate a spatial network for distinguishing temporal variations of biofuel production (Li et al., 2012). The economic, geographical and environmental models are always linked to obtain spatially explicit hot spots of biofuel production for a consideration of

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interconnected systems (Ballarin et al., 2011; Colantoni et al., 2016; Secchi et al., 2011), even at multiple scales (Elliott et al., 2014). One way is to create a variety of scenarios orientated for possible distributions or potentials of productive land or biofuel crops. Some researchers mainly followed the Intergovernmental Panel on Climate Change/Special Report on Emissions Scenarios (IPCC/SRES) scenarios of A1, A2, B1, and B2 (Hellmann and Verburg, 2010; Hoogwijk et al., 2009) by a consideration of variation in economic and cultural scales or in governmental roles and functions (Banse et al., 2011; Westhoek et al., 2006). Generally, the business-as-usual scenario has to be setup as a real simulation of resource/energy use following the current development pattern, but single factor-oriented scenario, e.g., environment oriented, economic oriented, etc., interprets a story of future scene under possible policies and demands (Bringezu et al., 2009; Fischer et al., 2010; Larsen et al., 2013). In the course of setting criteria for scenarios, a certain percentage of planned/expected target associated with biofuel production is proposed for simulation (Kavallari et al., 2014). Obviously, the potential alternative to land use options is close with oriented scenarios, serving for policy-making in time and space.

The available land for production is usually determined by multi-factors, including the agro-environmental factors of topography, climate, water, soil fertility, etc. (Ballarin et al., 2011; Li et al., 2012), the socio-economic factors of labors, legal reserves, investment, markets, institutions and policies, etc. (Ballarin et al., 2011; Giovannetti and Ticci, 2016; Piketty et al., 2009) and the interconnected factor of land present (Fiorese and Guariso, 2010). These factors are always interconnected and interacted with each other, which are involved in a weighed overlap in GIS platform to locate suitable plots. Some models have been widely used to analyze land suitability, such as CLUE/CLUE-s for forecasting loss of agricultural land (Fan et al., 2008; Verburg et al., 2002). On that, this study introduces Dyna-CLUE model, a revised version of CLUE-s model, to simulate land use in different scenarios through obtaining land demands and allocating their spatial distributions in separated cells (Castella and Verburg, 2007). The scenarios are simulated based on the degree of land suitability, dependent on the relative elasticity of the actual land use type to conversion measured by mixed agro-environmental and socio-economic factors (Verburg et al., 2002). The model dynamically simulates the competitive relation between different land use types and goes through an iterative process of selecting land use type in different cells until the allocated area in each cell is matched with demanded area, and finally obtains the forecast land use structure.

China is an emerging country regarding biofuel production. It is experiencing a great pressure posed on energy resources and environment, caused by rapid economy and increasing population, has to force governments to reconsider energy structure and related carbon emissions (Zhou et al., 2011). There has been assessment of biofuel production potential in China via forest inventories, but not so far for the whole land across China (Junfeng and Runqing, 2003). In sum, previous studies on China's biofuel production potential highlighted existing potentials for biofuel crops and also assessed associate carbon emissions, but not insufficient in quantitative evaluation of suitable land for biofuel production. Two main considerations are involved in this study to allocate lands suited for biofuels, one is on food security (cropland must be protected) and the other one is on suitable sites with two selected scenarios (planning-oriented and biofuel-oriented) to target biofuel production. Here we attempt (1) to select impact factors of estimating land conditions for possible biofuel production through spatial analysis, (2) to forecast land demands under two scenarios, and (3) to stimulate an alternative to available land for biofuel production potentials by Dyna-CLUE model and scenario analysis.

2. Materials and methods

2.1. General situation of study area

2.1.1. Scope of research

Our study focuses on entire China. It lies between 18-54°N and 73-135°E, is covered by highlands and deserts in the middle and western part and plains in the eastern part with a significant variation across its vast width. In the east, there are densely populated and infrastructure-improved cities and well drained land. Western part of China has marginal agro-environmental conditions for agriculture and less densely populated cities. China has 34 the provincial divisions (province, autonomous region, municipality, and special administrative region), composed of 23 provinces, 5 autonomous regions, 4 municipalities and 2 special administrative regions. In this study, the scope covers the majority of provincial units (31) except Hong Kong, Macao and Taiwan.

2.1.2. Energy production and consumption

In China, energy plays a critical role in urbanization and industrialization to support rapid economic growth and production demands, consequently, inducing an increase of energy production and consumption. The total energy consumption in China reached 1.04 billion tons of coal equivalent in 1991 at an annual growth rate of 5.10%, and the two values in 2012 up to 3.63% and 3.90%. As early as 2010, China reached a consumption of 3.25 billion tons of coal equivalent, accounting for 20.3% of global consumption, and exceeded USA to be the largest energy consumer over the world (Li and Han, 2014). The total primary energy production of 3.32 billion tons of coal equivalent in 2012 was nearly three times of 1991 level (Fig. 1). The rapid economic growth is linked with a higher demand for energy supply. This results in the annual energy production behind of annual consumption with increasing a gap during the last years (Fig. 1).

Coal and petroleum have always occupied an important position in energy consumption of China under the current economic settings. The consumption of coal and petroleum from 1991 to 2012 accounted for around 85% of the total energy consumption, and the total

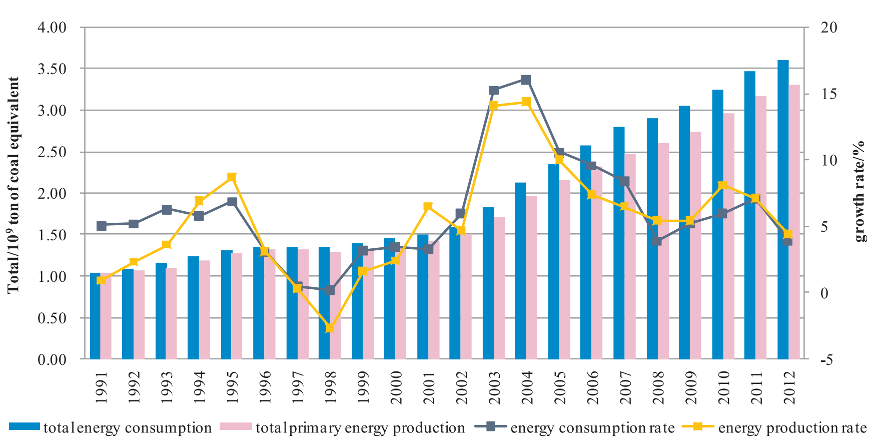

Fig. 1. Energy production and consumption in China from 1991 to 2012 (National Bureau of Statistics of People's Republic of China, 2014).