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Temporal-spatial variation analysis of agricultural biomass and its policy implication as an alternative energy in northeastern China

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ABSTRACT

Effective spatial-temporal analysis of the availability of agricultural biomass is crucial for cost-effective development of bioenergy. Using statistical data, simulation modeling, and a dynamic analysis framework, the authors assess the potential and distribution of regional agricultural biomass in Heilongjiang, China. The results indicate 32.48×10^6 t of agricultural biomass were available in 2003; this soared to 77.13×10^6 t in 2013. Gray correlation analysis demonstrated that precipitation, total population, mechanical power and agricultural planting structure largely influenced the availability of biomass resources. The support of corn oil storage plays an important role of agricultural planting structure. Statistical and Net Primary Production data were used to study the dynamic change in the availability of agricultural biomass. The growth rate of available biomass exceeded 2 t km^{-2} y^{-1} in most areas of the Sanjiang Plain, and ranged from − 1.5 to 2.0 t km^{-2} y^{-1} in the Songnen Plain. The establishment of a scientific resource management and scheduling platform is suggested to achieve the dynamic allocation and scheduling of agricultural biomass that will improve resource stability. The methods here can also be applied to other regions and provide baseline data for local authorities to further consider a strategy for bioenergy planning and development.

1. Introduction

Rapid economic development and increasing energy demands have recently created high levels of environmental pollution in China (Cai et al., 2008; Lu et al., 2015; Xu et al., 2014; Yanli et al., 2010). The Chinese government has been developing a creative energy generation portfolio with affordable, clean and green energy to partly replace fossil fuel energy and mitigate this situation (Elmore et al., 2008). In particular, urban energy is seeking innovative options to revitalize the urbanization development. Now, the use of biomass resources as energy is not anymore limited in rural regions and already moved into urban areas. Agricultural biomass as a kind of renewable resources can be collected, stored, transported and converted into energy, and has the controllable ability of peak load modulation of power grid (Fernandes et al., 2014). The use of agricultural biomass for energy purposes allows to improve the decarbonisation of the urban environment and the reliability of the energy supply (Banowetz et al., 2008; Lourinho and Brito, 2015; Welfle et al., 2014) and, additionally, as the labor demands on the collection and transportation chains, it can provide huge social benefits as increased employments and incomes.

However, a contradiction always exists between the scattered and unstable features of agricultural bio-resource feedstock and the concentrated industrial use of biomass production especially at medium and large scales (Wang et al., 2015). Actually, feedstock should have a balanced mechanism to achieve a dynamic equilibrium with the final use and industrial development of bioenergy (Becker et al., 2011). The energy strategies related to agricultural biomass assume the extensive use of primary biomass resources in local regions, which will increase an unreasonable competition between biomass facilities or plants needed to provide sufficient feedstock (Esteban and Carrasco, 2011; Fiorese et al., 2013). Evaluating the amount of available agricultural resources involves considering the assessment of the extent of realistic and viable economic performance of biomass energy on the energy market (Adams et al., 2015). Meanwhile, the availability of indigenous agricultural biomass provides a renewable resource through annual harvesting and is influenced by a variety of natural and anthropogenic factors. If a country wishes to increase the use of indigenous agricultural resources because of ongoing energy demands, an in-depth understanding of how various factors or drivers influence the availability of biomass resources to the local and national bioenergy sectors must be conducted (Welfle et al., 2014).

The development of an economically efficient approach to convert-

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ing agricultural biomass to energy will require an assessment of the regional distribution of available straw; this will allow researchers to identify an appropriate scale of conversion technology that optimally reduces straw collection and transportation costs (Banowetz et al., 2008; Song et al., 2016). Considering the trends in the variation of the density and distribution of biological resources is important. This type of data is needed by local governments and policy makers in their efforts to establish medium- and long-term planning for the development of biomass resources, and for enterprises and planners to arrange for the development and implementation of projects related to biomass resources.

The dynamic temporal-spatial distribution of agricultural biomass exhibits a high degree of heterogeneity in specific areas; this heterogeneity may lead to significant effects on the subsequent feedstock of bioenergy use (Dymond et al., 2010; Tittmann et al., 2010). Substantially focusing on the temporal and spatial variations in the distribution of agricultural biomass can provide realistic technical support for local energy sectors that will allow planners to determine priority zones for the development and use of regional bioenergy. This type of data may enable policy advocates or policy makers to identify particular planning and development needs and allow them to target bottlenecks in the short- or medium-terms, or to assess the degree to which current regional projects and practices are conducive to newly developed objectives. The establishment of effective regional biomass resource assessment methods from a dynamic perspective would also help reduce any unreasonable development of land resources.

Geographic Information System (GIS) technology provides an appropriate spatial processing platform that will help planners to analyze and develop spatial projects; recently, GIS has been used in a number of studies to assess the potential of using biomass for various purposes, including as an energy source (Fernandes et al., 2014). Elmore et al. (2008) presented a method that employs national Net Primary Productivity (NPP) data sets from the moderate-resolution imaging spectrometer (MODIS); NPP is expressed as gross primary productivity minus the autotrophic respiration of vegetation, which is one of the key indicators of vegetation productivity. In addition, detailed land cover maps produced from Landsat-enhanced thematic mapper plus (ETM+) data have been used to calculate the spatial distribution of rice straw (Elmore et al., 2008). A study disaggregated biomass potentials derived from statistical crop data using NPP as weighting data to optimize the distribution of biomass energy (Gehrung and Scholz, 2009). Sun et al. (2013) used the methodological framework from Gehrung and Scholz (2009) to estimate the distribution of agricultural and forestry residues by incorporating spatial and statistical data in Fujian Province, China (Sun et al., 2013). However, these studies mainly used static data related to a given year for planning, and few studies have considered the dynamic variation of the distribution of biomass.

This paper evaluates the total amount and the variation in the temporal-spatial distribution of the availability of agricultural biomass from a dynamic perspective, and identifies the substantial drivers that can induce the amount of variation in indigenous agricultural resources available for potential use by the bioenergy sector. This study analyzed conditions in Heilongjiang, China. Heilongjiang is fertile ground for the industrial development of biomass energy using agricultural biomass resources as raw materials, such as biomass briquettes, biomass liquefaction projects, and biomass power generation. This study uses a GIS platform to combine statistical analysis and NPP modeling and simulates the regional dynamics of the spatial variations of biomass in the research area. Moreover, this study will bring together and allow the calibration of a wide range of variables and potential factors that collectively may influence the indigenous availability of agricultural biomass. Gray correlation analysis is used to assess the effects of distinct drivers. Then, the statistical methods and mathematical simulation methods are used to systematically study the spatial and temporal distribution and characteristics of agricultural biomass resources in the research area. Although this research focuses on a regional scale in Heilongjiang, China, the analysis is also applicable to other regions or countries where a greater understanding of indigenous biomass availability is sought.

2. Overviews of energy consumption and bioenergy policy

2.1. Energy consumption during urbanization process

With the economic and social development and infrastructure construction improvement, the level of urbanization in Heilongjiang has been constantly increased. From 1990s, the expansion of urban scale encourage people migration, urbanization began to enter a period of rapid development. Because of the process of urbanization combined with the rapid economic development, the province's Gross Domestic Product (GDP) was 405.74 billion yuan in 2003 and up to 828.8 billion yuan in 2010. The total urban population was 20.21 million people in 2002 and increased into 21.23 million people by the end of 2009.

Previous studies indicates that there exists a one-way Granger causality and a co-integration relationship between Chinese urbanization and energy consumption (Liu, 2007), that also indicates the increased level of urbanization can increase energy consumption. In Heilongjiang, energy consumption significantly augments with the rapid development of urbanization. As per Heilongjiang Energy Statistical Yearbook, urban energy consumption was 57×10^6 t of standard coal (tce) in 1990 and approximately reached 100×10^6 tce in 2012 (Fig. 1).

As the study area, Heilongjiang Province is located in the northeast region of China (Fig. 2). Heilongjiang is the main and notable energy-producing (petroleum and coal) and coal-export province in China, which also plays an important role as energy base in China's urbanization construction process. However, fossil energy production grew slowly (Fig. 1), that the annual production capacity of fossil energy was 138×10^6 tce in 2004 and decreased to 121×10^6 tce in 2012. There is a huge contradiction between the rapid increase in energy demand and decrease in fossil energy production. Previous studies have predicted that growing energy demand may exceed energy production growth rate in Heilongjiang (Xu et al., 2013). The local government of Heilongjiang now is facing a severe challenge about sustainable energy development. One solution is to find a new way on green energy to reduce the demand for fossil fuels (Liu et al., 2007) and to increase the proportion of biomass in the energy mix (Shen, 2011).

2.2. Bioenergy policy

Chinese government encourages the energy utilization of agricultural biomass in “the national renewable energy medium and long-term development plan in China”. In 2008, the Ministry of Finance established funds to support the straw industrial development, and formulated “Interim Measures” on financial subsidies for straw energy utilization. “Interim Measures” explained that this fiscal subsidy only supports enterprises engaged in straw energy production; enterprises

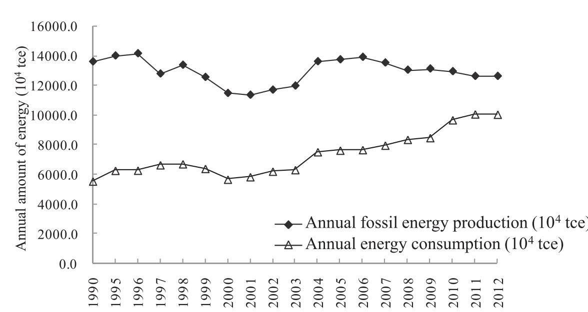

Fig. 1. Energy production and consumption.