Non-grain fuel ethanol expansion and its effects on food security: A computable general equilibrium analysis for China

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A B S T R A C T
Concerning food security, China has launched non-grain fuel ethanol projects with potential land. However, there are concerns and facts, such as feedstock price rise, regarding its implications on quantity of food supply and food price. This study aims to better understand the impacts of expanding non-grain fuel ethanol on food price, supply and consumption using a CGE (computable general equilibrium) model. The investigation is divided into two scenarios, no supply of potential land and supply of potential land. The results show that: an increase in the fuel ethanol production raises food prices under both scenarios; and food supply and consumption can be ensured when there is a supply of potential land. Also, the simulated results predict adequate and quality potential land supply is one of the most important aspects to ensure food security in China. In addition, financial and trade policy implications are proposed.

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1. Introduction

Mainly concerning the threat to national security by persistently high oil price and increasing reliance on imported oil, also taking into account the digestion of excessive grain and the reduction of carbon emission [1], the Chinese government began to use corn to produce fuel ethanol in 2002. Under the impetus of the Chinese government, fuel ethanol production skyrocketed and reached 1.92 million tons in 2012 [2]. Currently, China is the third largest fuel ethanol producing and consuming country in the world, next to Brazil and the United States.

However, while promoting fuel ethanol, the Chinese government has been considering another important issue — food security [3]. Food security is defined as “secure access to enough food at all times” [4]. Accordingly, the major subdivision of food security can be expressed in terms of adequacy of the food supply and stability of both the supply and access to food [5]. Adequacy of the food supply means the food supply can meet the demand for nutritious and safe food at national, regional and household level. Stability of both the supply and access to food implies the long-term stable supply at a reasonable price. Therefore, the above definition clearly addresses that quantity of food supply and food price are two pivotal elements of food security.

Given that corn is currently used for food, feedstock, fuel ethanol and other products in China, it is tempting to conclude a priori that the expansion of corn-based fuel ethanol would put a strain on food supplies and cause worrisome increases in food prices [6–12]. This was recognized by the Chinese government. The NDRC (National Development and Reform Commission) and the Ministry of Finance jointly issued the Notice Concerning Strengthening the Management of Bio-fuel Ethanol Projects and Promoting the Healthy Development of the Industry to guide further development of fuel ethanol. Non-grain fuel ethanol has become the future development direction. The first non-grain fuel ethanol project — the Guangxi Beihai project began production using cassava as the feedstock. When the operation of the project was started in the first quarter of 2008, the price of fresh cassava increased from CNY (China Yuan) 400 per ton to CNY 600–700 per ton, which encouraged farmers to expand cassava planting. While the sowing area of rice and economic crops decreased from 37.2% to 36.4% up to 47.8% in the sowing area structure of Guangxi province from 2008 to 2009, the sowing area of cassava increased from 3.9% to 4.0% [13]. The above minor changes of the sowing structure were considered to indicate that some farmers turned to grow cassava instead of grain and other crops.

Considering the possibility of land competition between ethanol and food crops, the Chinese government stimulates non-grain fuel ethanol production.
ethanol expansion with potential saline land, barren hills and wasteland, totaling 6.67 million ha [14]. According to the adaptation to geographic conditions, it is proposed that the northern, central, southeastern and southern China should focus on sweet sorghum, sweet potatoes and cassava, respectively (Table 1) [15]. Sweet sorghum is the most potential as a feedstock for fuel ethanol production in the short term because of its drought resistant feature, high ethanol conversion efficiency and largest area of potential land for planting [16]. Cassava based ethanol projects have been under operation since 2008 and in expansion [17]. However, like corn, sweet sorghum and cassava are agricultural crops which share production factors, such as capital investment and agricultural labors, not only for land, with other crops. Therefore, a rise in fuel ethanol demand is supposed to increase the price of sweet sorghum and cassava, and furthermore lead to centralization of production factors to these two sectors, and thus has negative effects on the production of other crops.

The objective of this paper is to conduct an economic analysis to resolve the question: whether expanding fuel ethanol production from sweet sorghum and cassava can ensure national food security? Specifically, it is very important to understand whether an increase in fuel ethanol production from sweet sorghum and cassava grown on potential land raises food prices and causes food supply crisis. Moreover, it is also necessary to know to what extent does this response to national food security. Although there are a few studies on the impacts of corn-based fuel ethanol on food security [3,18–23], and the impacts of non-grain fuel ethanol on energy and environment [24–26], little study is available for the effects of non-grain fuel ethanol on food security in China.

This study employs the computable general equilibrium (CGE) model to analyze the wide economic and social consequences of expanding fuel ethanol production from sweet sorghum and cassava. For the purpose of this study, the analysis with the CGE model focuses on changes in several indicators at agricultural and regional levels, such as output, producer price, exports, imports, household income, and other micro indicators. The extent of the impacts is expressed by the percentage changes from the base value following fuel ethanol expansion.

Section 2 of this paper provides an overview of sweet sorghum and cassava based fuel ethanol expansion in China. Section 3 explains the model and its calibration, especially, the database – SAM (the Social Accounting Matrix). Section 4 designs the simulations and reports the results of the simulations, and Section 5 concludes with implications for fuel ethanol policy.

2. Sweet sorghum and cassava based fuel ethanol expansion in China

In the production process of fuel ethanol, one of the three main types of raw materials, including sugars, starches and cellulose materials, is necessary. Among them, sugar can be converted into ethanol directly while starches and cellulose materials must be hydrolyzed to fermentable sugars to produce ethanol [27,28]. Because sweet sorghum stalks have very high sugar content and cassava roots are highly rich in starch, they are good options for fuel ethanol production. Furthermore, sweet sorghum and cassava can grow well on marginal lands whereas other agricultural crops such as rice, corn and wheat cannot [29]. Therefore, sweet sorghum and cassava are chosen for fuel ethanol development by the Chinese government.

2.1. Sweet sorghum based fuel ethanol development

Sweet sorghum has a high sugar content of 16%–20% [14]. It is estimated that approximately 16–18 tons of sweet sorghum can be used to produce 1 ton of fuel ethanol with the current technology [30]. Presently, sweet sorghum is mostly used for alcohol production in China [31]. Major areas for sweet sorghum planting are Northeast, North and Northwest China and some areas of the Huanghuai River Delta. Sweet sorghum is considered to be the most important feedstock used in fuel ethanol production for the future because China has a lot of saline and alkaline land for planting [32]. In China, the saline and alkaline land is approximately 10 million ha [33]. Suppose only one-fifth of the 10 million ha of saline-alkaline land is used for planting sweet sorghum, and the output in these lands is only half of normal soil, the output of sweet sorghum would be 60 million tons every year, using for 3.5 million tons fuel ethanol production [34].

Considering the large-scale potential land source and the adaptability to marginal land of sweet sorghum, the Chinese government planned to expand fuel ethanol from sweet sorghum in Inner-Mongolia and Shandong beginning 2011 (Table 2).

Inner-Mongolia is beneficial to accumulate sweet and suitable for sweet sorghum planting, as it has rich solar sources, high actively accumulated temperature, and great difference in temperature between day and night. In Inner-Mongolia, COFCO (China Oil & Foodstuffs Corporation) and the Wuyuan County government, corporating with Tsinghua University, has finished fuel ethanol pilot using solid state fermentation in 2006. Currently, since Bayan Nur City in Inner-Mongolia has 333 thousand ha to plant sweet sorghum, a state-level “biomass energy base” with 300 thousand tons sweet sorghum based fuel ethanol project is under construction, for which, sweet sorghum acreage is planned to reach 67 thousand ha in Bayan Nur City by 2015 [35]. A sub-project with annual production of 100 thousand tons began its construction in April 2010, which would use 100 thousand hm² of marginal land, providing jobs for 30 thousand persons and achieving 300 thousand tons of reduction in carbon dioxide emission [36].

Shandong is suitable for sweet sorghum cultivation and a total area of 800 ha is already planted with this crop currently. CNPC (China National Petroleum Corporation) and the Shandong

<table>
<thead>
<tr>
<th>Region</th>
<th>Energy crop</th>
<th>Reclaimable grassland</th>
<th>Reclaimable saline areas</th>
<th>Reclaimable mud flat</th>
<th>Other reclaimable</th>
<th>Total</th>
<th>Potential for 2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeast China</td>
<td>Sweet sorghum</td>
<td>214.6</td>
<td>142.0</td>
<td>62.5</td>
<td>9.7</td>
<td>428.8</td>
<td>214.0</td>
</tr>
<tr>
<td>North China</td>
<td>Sweet sorghum/sweet potato</td>
<td>190.2</td>
<td>141.2</td>
<td>124.5</td>
<td>47.5</td>
<td>503.4</td>
<td>252.0</td>
</tr>
<tr>
<td>Loess Plateau</td>
<td>Sweet sorghum/sweet potato</td>
<td>47.9</td>
<td>12.0</td>
<td>2.9</td>
<td>17.6</td>
<td>80.4</td>
<td>40.2</td>
</tr>
<tr>
<td>Northwest China</td>
<td>Sweet sorghum</td>
<td>1933.7</td>
<td>341.1</td>
<td>28.1</td>
<td>1360.8</td>
<td>3663.7</td>
<td>1832.0</td>
</tr>
<tr>
<td>Middle and East China</td>
<td>Cassava/sweet sorghum</td>
<td>336.4</td>
<td>5.4</td>
<td>227.6</td>
<td>62.2</td>
<td>631.6</td>
<td>316.0</td>
</tr>
<tr>
<td>South China</td>
<td>Cassava</td>
<td>62.1</td>
<td>0.4</td>
<td>51.1</td>
<td>6.4</td>
<td>120.0</td>
<td>60.0</td>
</tr>
<tr>
<td>Southwest China</td>
<td>Sweet potato</td>
<td>237.1</td>
<td>0.2</td>
<td>22.5</td>
<td>35.2</td>
<td>295.0</td>
<td>148.0</td>
</tr>
<tr>
<td>Qingzang Plateau</td>
<td>None</td>
<td>162.6</td>
<td>49.9</td>
<td>2.3</td>
<td>12.5</td>
<td>227.3</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>3615.8</td>
<td>800.5</td>
<td>547.2</td>
<td>1710.6</td>
<td>6674.3</td>
<td>3220.0</td>
</tr>
</tbody>
</table>

Sources: [14,31].
provincial government signed a cooperation framework agreement on the development of bio-energy industry in 2007. According to this agreement, CNPC will build a 200,000 ton–sweet sorghum based fuel ethanol demonstration plant in Shandong.

2.2. Cassava based fuel ethanol expansion

Cassava has a high starch content of 25%–35% [14]. Approximately 72 tons of fresh cassava is required to yield 1 ton of fuel ethanol production. Because of its high yield and high ethanol conversion rate, cassava is considered by China’s leaders as the second most important fuel ethanol feedstock [31]. Cassava is tolerant to drought and barren land and widely cultivated in tropical and subtropical regions. Cassava is mainly distributed in areas such as the Hainan, Guangxi, Guangdong, Yunnan, Fujian, Jiangxi and Hunan provinces of China. In 2009, the total harvested area and total production of cassava was 381.2 thousand ha and 7.27 million tons, respectively [14]. From the regional distribution point of view, the area and production of cassava in Guangxi covered 61% and 63% of the total, respectively, ranking first among the production areas. Moreover, the potential for cassava cultivation in China is expansive. The potential area is more than 1.4 million km² [37]. The land, estimated by the current yield per hectare, can be used to plant 22.68 million tons of cassava, which can produce 3 million tons of fuel ethanol [37].

Based on the regional land potential and raw material supply, cassava-based fuel ethanol production has been planned for expansion in Guangxi, Guangdong and Sichuan beginning 2011 (Table 2).

Guangxi is located in a mountainous area. Soils are unfertile and acidic, and most areas are dry. The natural conditions are suitable to plant cassava. Guangxi is the first province to use cassava instead of grain to produce fuel ethanol. COFCO has commenced production of cassava-based fuel ethanol since 2008. With the annual production capacity of 200 thousand tons, the supply is able to satisfy the demand of fuel ethanol in Guangxi. In order to expand the production to supply Yunnan, Guizhou, Guangdong and Hongkong, COFCO has planned new cassava-based fuel ethanol project in Guizhou with 200 thousand tons. In addition, other two projects in Wuzhou and Laibin with the same production capacity, which are launched by China National Petroleum Corporation (CNPC), are under feasibility study.

New cassava-based fuel ethanol projects in Guangdong and Sichuan have been planned by Henan Tianguan Fuel Ethanol Co., Ltd. which is the second largest fuel ethanol plant in China. The total production of these two projects will achieve 300 thousand tons. To meet the requirements of fuel ethanol expansion, Henan Tianguan Fuel Group has already had a cassava plantation base with 50 thousand ha, sufficient to support a 300,000-ton-per-year fuel ethanol production [38].

3. CGE model

3.1. Overview

CGE models have their roots in the input–output theory that are widely used for economic, social and environmental planning and evaluation because it is effective in grasping the inter-sectoral linkages [39,40]. However, input–output models have some limitations which simulated the development of CGE models. The limitations are mainly reflected by the model assumptions, including fixed prices, unlimited factor supply, and fixed shares of factor and intermediate inputs in the production process [41]. Under these assumptions, input–output model cannot show the substitution among production inputs, and the responsive behavior of producer and consumer to changes in relative prices [39].

The pioneering CGE model was the Norwegian multisectoral growth model developed by Ref. [42]. CGE models are suitable for analyzing contemporary policy issues in a competitive market economy because they feature the price mechanism that plays an important role in an economy. The price mechanism is powerful to solve the complicated trade–off problems generated in an economy which cannot be realized by input–output models. Economic agents make their decisions about economic activities according to changes in market prices under given resource and technology constraints. Moreover, market equilibrates demand and supply by adjusting prices. Because CGE models can quantify these above market behavior and changes, they are used widely in various policy analyses.

A CGE model is typically used to simulate policies or exogenous events. A base case is constructed to reflect the observed reality. Scenarios are then built by altering some exogenous variables or parameters of the model to reflect the intended or experienced changes. Post-shock equilibrium is computed, making it possible to quantify the overall economic impacts of the introduced modifications [43].

This study analyzes the fuel ethanol industry, food markets, land and labor inputs, household welfare and government action. These issues related to several aspects of the macro-economy. Fig. 1 displays the general structure of the CGE model in this study. CGE models can grasp most of these relevant aspects and can, therefore, be widely used to analyze energy policies [44]. Clearly, analyzing such economy-wide impacts cannot be carried out with a partial equilibrium framework.

Table 2

<table>
<thead>
<tr>
<th>Company</th>
<th>Location</th>
<th>Feedstock</th>
<th>Capacity (ton/year)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>China Resources Alcohol Co. (COFCO)</td>
<td>Heilongjiang</td>
<td>Corn</td>
<td>370,000</td>
<td>Opened 2001</td>
</tr>
<tr>
<td>Jilin Fuel Ethanol Co., Ltd.</td>
<td>Jilin</td>
<td>Corn</td>
<td>600,000</td>
<td>Opened 2003</td>
</tr>
<tr>
<td>Henan Tianguan Fuel ethanol Co., Ltd.</td>
<td>Henan</td>
<td>Wheat/Corn/Cassava</td>
<td>500,000</td>
<td>Opened 2001</td>
</tr>
<tr>
<td>Anhui BBCA Biochemical Co.</td>
<td>Anhui</td>
<td>Corn</td>
<td>440,000</td>
<td>Opened 2005</td>
</tr>
<tr>
<td>Guangxi COFCO Biomass Energy Co., Ltd.</td>
<td>Nanning (Guangxi)</td>
<td>Cassava</td>
<td>200,000</td>
<td>Opened 2007</td>
</tr>
<tr>
<td>Guangxi COFCO Biomass Energy Co., Ltd.</td>
<td>Guigang (Guangxi)</td>
<td>Cassava</td>
<td>200,000</td>
<td>Planned</td>
</tr>
<tr>
<td>CNPC (China National Petroleum Corporation)</td>
<td>Wuzhou (Guangxi)</td>
<td>Cassava</td>
<td>200,000</td>
<td>Feasibility study</td>
</tr>
<tr>
<td>CNPC (China National Petroleum Corporation)</td>
<td>Laibin (Guangxi)</td>
<td>Cassava</td>
<td>200,000</td>
<td>Feasibility study</td>
</tr>
<tr>
<td>China Resources Alcohol Co. (COFCO)</td>
<td>Inner-Mongolia</td>
<td>Corn/Sweet sorghum</td>
<td>300,000</td>
<td>Planned</td>
</tr>
<tr>
<td>Qing Yuan Long Tang</td>
<td>Guangdong</td>
<td>Cassava/Sugarcane</td>
<td>100,000</td>
<td>Planned</td>
</tr>
<tr>
<td>CNPC (China National Petroleum Corporation)</td>
<td>Shandong</td>
<td>Sweet Sorghum</td>
<td>200,000</td>
<td>Planned</td>
</tr>
<tr>
<td>Henan Tianguan Fuel ethanol Co., Ltd.</td>
<td>Guangxi</td>
<td>Cassava</td>
<td>200,000</td>
<td>Planned</td>
</tr>
<tr>
<td>Henan Tianguan Fuel ethanol Co., Ltd.</td>
<td>Guangdong</td>
<td>Cassava</td>
<td>100,000</td>
<td>Planned</td>
</tr>
<tr>
<td>Henan Tianguan Fuel ethanol Co., Ltd.</td>
<td>Sichuan</td>
<td>Cassava</td>
<td>200,000</td>
<td>Planned</td>
</tr>
</tbody>
</table>

Source: [17].
The model is constructed according to the purpose of this study, focusing on the effects of non-grain fuel ethanol expansion with potential land on national and regional food security. Therefore, in this model, land and agricultural labor inputs are divided into regional types to evaluate the impacts on factor mobility. On this basis, income and expenditure impacts on rural household in different regions can be observed because a major part of their income is from labor and land input in China. Moreover, potential land is introduced according to the Chinese policy to investigate the effects of reducing the occupation of existing arable land.

The model is a system of equations describing the behavior of producers, consumers and government, and the equilibrium conditions and constraints of the economy for factors, commodities, savings and investment, and rest of the world. There are six blocks included in this model: production, households, trade, government, savings and investment, and market equilibrium. In order to highlight key points, production block and household block are presented in detail.

3.2. Model blocks

3.2.1. Production block

Producers maximize profits subject to technological constraints. As shown in Fig. 2, the technology of production is represented by a nested CES (constant elasticity of substitution) and Leontief function. At the top level a choice is made by the Leontief production function between two composite goods: a value-added factor and an intermediate input composite. This means there is no substitutive relationship between the value-added and intermediate input composite. The Leontief production function is expressed as follows:

$$Y = \min_{\frac{b_1}{ab_1}, \ldots, \frac{b_n}{ab_n}}$$  \hspace{1cm} (1)

where $Y$ is the aggregate output of the firm, $b_1, \ldots, b_n$ are the aggregates of various inputs, and $ab_1, \ldots, ab_n$ are the input requirement coefficients.

The value-added factor composite is obtained by capital-land composite and labor composite using a CES production function. The intermediate input composite is produced using the Armington assumption [45] with a CES technology to decide the domestic input and foreign input. At the third level, a CES function describes
the substitution possibilities for capital and land composite in capital-land composite input, and agricultural labor composite and non-agricultural labor in labor composite input. The CES function can be expressed as follows:

\[ Y = A \left( \sum_{i=1}^{n} \delta_i X_i^p \right)^{-\frac{1}{p}} \]  

(2)

where \( Y \) is the output of production, \( X_i \) is the \( i \)-th input factor, and \( A, \delta, \) and \( p \) are the parameters.

For land, different regional land types and agricultural labor types can be chosen at the fourth-level nest with Cobb-Douglas production function. The Cobb-Douglas function is expressed as follows:

\[ \hat{Y} = \hat{A} \prod_{i} \hat{X}_i^\hat{\beta} \]  

(3)

where \( \hat{Y} \) is the output of production, \( \hat{X}_i \) is the \( i \)-th input factor, and \( \hat{A} \) and \( \hat{\beta} \) are the parameters.

Each nesting level is characterized by a specific substitution elasticity, which shows to what extent the factors can be substituted for each other.

3.2.2. Household block

For the household block, third-stage nested CES functions are used to characterize households’ behaviors for maximizing total household utility subject to budget constraints (Fig. 3). On the first level, disposable income is allocated to consumption and saving. The distribution of disposable income between consumption and savings is decided by the capital interest and commodity composite price. On the second level, total consumption is distributed to automobile, fuel composite and other commodity composite. The percentages of respective products possessed by household depend on the consumption budget and the relative prices of automobile, fuel composite and other commodity composite. On the third level, total fuel consumption is assigned to fossil fuel and non-grain fuel ethanol. The household consumption choice between fossil fuel and fuel ethanol is also determined by the fuel prices. Therefore, subsidy to fuel ethanol production and consumption would stimulate the household consumption on fuel ethanol.

3.2.3. Other blocks

For trade, although China has become an important country for world trade, the small, open economy assumption is adopted because the share of trade is not so high as to make China a price-setter. Regarding imports, Armington’s assumption is used to make a decision between the imports originating from the rest of the world and the domestically produced goods by imperfect substitution. For exports, a CET (constant elasticity of transformation) aggregation function between domestic and foreign sales is used. The CET function is expressed as follows:

\[ Q = B \left( \sum_{i=1}^{G} \gamma_i Y_i^p \right)^{-\frac{1}{p}} \]

where \( Q \) the supply-side output, \( Y_i \) are the output levels of various products, and \( B, \gamma \), and \( p \) are the parameters.

In the model, government saving is given at a fixed rate; investment is endogenous and equal to total savings; thus, the model has neoclassical closure.

3.3. Model calibration

The model is calibrated to a 2007 SAM with the data from a variety of sources. The main ingredient utilized for estimating the macro SAM of China for 2007 is the 2007 Input–Output Table of China with 135-Commodity by 135-Commodity. Additionally, other statistical materials, including the China Statistical Yearbook 2008–2009, published by the National Bureau of Statistics of China, the Almanac of China’s Finance and Banking 2008, compiled by The People’s Bank of China, and the Finance Year Book of China 2008, completed by the Ministry of Finance, People’s Republic of China, were adopted. However, the macro SAM only provides a comprehensive framework for description of all of the macro-economic activities. It is necessary to construct a disaggregated SAM to analyze the study in more detail. There are two difficulties in the construction of the disaggregated SAM, which are agricultural sector division and fuel ethanol sector establishment.

Because there is only one farming sector in the 2007 Input–Output Table of China, the farming sector should be divided into food sectors (rice, wheat and corn), feedstock sectors (cassava, sorghum and potato) and other crops according to the purpose of this study. The problem is lack of statistical data for details on agricultural production sectors in China [46]. Presently, the GTAP (the Global Trade Analysis Policy) database is widely used and helped to construct intermediate input accounts in most studies. However, the agricultural sectors in the GTAP table differ greatly from the apparent structure of agriculture in China for output values and intermediate structure. Therefore, intermediate demand and supply transactions should be constructed with some other data materials. The compilation of agricultural product costs and income data for 2007 from the National Agricultural Production Cost and Revenue Information Summary 2008 provides information on the cost structure. Estimates of intermediate supply and final consumption are calculated using the data of Crops Primary Equivalent from the FAO (Food and Agriculture Organization of the United Nations) Statistical Database.

For establishing fuel ethanol sector, the input and output values are separated from “Manufacture of Alcohol” sector in the 2007 Input–Output Table. First, the intermediate input cost structure identifies the following cost items: raw material, supplementary material, water, power, coal and vapor, while the value added contains capital and non-agricultural labor input. Based on the Chinese government’s policies on fuel ethanol development, the indirect tax for fuel ethanol sector is zero because the value added tax (normally 17%) on fuel ethanol production is refunded at the end of each year. Certainly, under the current condition of fuel ethanol in short supply, there is no trade for it. Finally, we calculate the total output value by multiplying the producer price of fuel ethanol and fuel ethanol production in 2007 to obtain the cost and supply values for the ethanol sector in the disaggregated SAM. There are no exports and stocks for fuel ethanol.
In addition, we were required to obtain estimates for the elasticities based on econometric evidence or refer to related studies [47]. In our model, the elasticity of substitution between household consumption and saving and the elasticity of substitution among composite goods, automobile and composite fuel consumption were obtained by non-linear estimation. The other elasticity parameters are referred to related studies, shown in Table 3.

3.4. Sensitivity analysis

Sensitivity analysis should be carried out to achieve the robustness in CGE modeling since the model output may be highly dependent on parameter assumptions [48,49]. In this study, a sensitivity analysis is conducted to examine the macroeconomic impacts of the elasticity of substitution between fossil fuel and non-grain fuel ethanol.

Ranges of values for the elasticity of substitution between non-grain fuel ethanol and fossil fuel have been tested to observe the sensitivity of macroeconomic results to the parameter. In the sensitivity analysis, the alternative values tested range from 0 to 5. The upper value represents nearly perfect substitution. There is a dramatic change occurs in the elasticity value from 2 to 2.5. It means the elasticity change has relatively minimal impact on macroeconomic variables in the value from 0.5 to 2 and from 2.5 to 5. A comparison to the above two segments of 0.5–2 and 2.5–5 indicates that there are large variations in total investment, government consumption and interest rates, which change from positive to negative values. This may be because an overestimated segment would overstate the reduction of fossil fuel production and increases in fuel ethanol production, and thus capital and non-agricultural labor in the gasoline sector would be released to other sectors. Due to its large benchmark, capital and non-agricultural labor would be expected to meet fuel ethanol development. However, owing to the characteristics of land-intensive and labor-intensive farming sectors, wage rates of agricultural and non-agricultural labor and land prices rise, while interest rates of capital fall from the baseline. A fall in the interest rate would decrease saving absorption, further leading to investment declines and hindered macroeconomic development. The above changes, especially, a decrease in total absorption as shown in the segment of 3–5, are not commonly expected for China’s future development. Therefore, the value range of 0.5–2 should be adopted for analysis.

In this segment, under the same level of government subsidies, the share of fuel ethanol in the total gasoline consumption increases as the elasticity increases. Therefore, the value of 2 can be used for analysis in this study.

3.5. Solutions procedures

The model designed in this study is highly nonlinear, and has been implemented in GAMS (General Algebraic Modeling System), a powerful computer package that allows model implementation while also paying attention to syntax rules [50]. The solution procedure involves two steps. The first step is to input GAMS code to describe the logical structure of the model by incorporating the data from the SAM, the functional specification and behavioral equations. The computer code ends with bounds and initial values of the variables, control commands, model statement, and output-generating sentences [51]. The second stage is to solve the model by using the CONOPT3 solver. CONOPT is an alternative solver to MINOS and other NLP (non-linear problem) solvers available for use with GAMS.

4. Simulation analysis

4.1. Simulation design

The scenarios are based on China’s renewable energy policy. According to China’s Medium to Long-term Renewable Energy Development Plan (2020) (Table 4), fuel ethanol production will be 10 million tons a year by 2020. Two simulation scenarios are established (S1 and S2) to achieve this quantity goal. However, the model used in this paper is a static CGE model of an open economy. The main purpose of this analysis is to quantify the impacts of non-grain fuel ethanol expansion on food production, price and trade.

Table 5 shows the potential production of non-grain fuel ethanol. The production of fuel ethanol is 1.50 million tons in 2007, including 0.10 million tons for cassava million tons and 1.40 million tons for grain ethanol. It can be seen that the production limit of cassava based fuel ethanol is 1.08 million tons based on the land limit in the region of middle and lower Yangtze River and south China. If we assume the potential production of cassava based fuel ethanol will be all used, in addition to the production in 2007, the production of cassava based fuel ethanol should be increased by 0.98 million tons. Moreover, in order to meet the production target for 2020, the production increment of sweet sorghum based fuel ethanol should be increased by 7.52 million tons. Additionally, potential land supply is also considered in the simulation. The reserved land in Guangdong, Jiangxi, Yunnan, Hainan and Guangxi is assumed to be reclaimed for cassava planting, in Inner Mongolia and Shandong is assumed to be reclaimed for sweet sorghum planting. The potential land inputs for the above provinces can be calculated based on the marginal arable land suitable for growing fuel ethanol crops from Ref. [14]. Therefore, two scenarios are designed, shown by Table 6.
Scenario 1: the current fuel ethanol production using grain levels off; cassava-based fuel ethanol increases by 0.98 million tons; and sweet sorghum-based fuel ethanol increases by 7.52 million tons; no potential land supply.

Scenario 2: the current fuel ethanol production using grain levels off; cassava-based fuel ethanol increases by 0.98 million tons; and sweet sorghum-based fuel ethanol increases by 7.52 million tons; potential land supply for ethanol feedstock cultivation.

The simulations are performed by increasing fuel ethanol production by 8.5 million tons from the baseline scenario to reach the planned target (10 million tons). We estimate the effect of fuel ethanol expansion on food prices, output, and consumption, which are food security indicators. In the Scenario 2, exogenous potential land supply shares the total land requirements induced from fuel ethanol production goal, which affects production factor distribution and furthermore cause the variations in the commodity, factor and capital market.

### 4.2. Key findings

#### 4.2.1. Food price

As expected, expanding fuel ethanol production will lead to an increase in food prices, which are shown in Fig. 4. To meet the fuel
Fig. 6. Food consumption and import variations (%).

Fig. 7. Rice consumption variations by regional rural household (%).

Fig. 8. Wheat consumption variations by regional rural household (%).
ethanol production target, the demand for cassava and sweet sorghum will increase. As demand rises, prices for these feedstocks rise, and thus, indirectly affect the factor supply and demand. Land, capital and labor move to the feedstock sectors from other crop sectors, such as paddy rice, wheat and corn. An increase in the demand for land, capital and labor in the feedstock sectors leads to factor price rise. As shown in Fig. 4, under Scenario 1, composite factor price increases by 1.970%, 1.941% and 2.026% in the sectors of paddy rice, wheat and corn, respectively. Owing to potential land input under Scenario 2, the relatively small increase in land price results in a light increase in composite factor price. Because the producer price is decided by the composite factor and intermediate commodity prices, the producer price also rises in Scenario 1 and Scenario 2. Furthermore, the producer price increases more substantially in Scenario 1 than in Scenario 2. Additionally, the variations of import price and export price depend on the variation of exchange rate because the small, open economy assumption is adopted. The above analysis indicates that fuel ethanol production has a negative impact on food price though the impact is lighter when potential land can be used. Food price rise would affect food consumption, and furthermore, food security.

4.2.2. Food supply

As shown in Fig. 5, an increase in cassava and sweet sorghum demand reduces output in other crop sectors. For instance, the largest fall occurs in fruit sector and sugarcane sector, which decreases by 0.972% and 0.900%, respectively. However, the output of food crops is less affected. Except paddy rice, the output of wheat and corn both increases by 0.149%. In contrast to this increase, the domestic supply of wheat and corn decrease with exports increase because export prices are higher than producer prices. Under Scenario 2, the output of paddy rice, wheat and corn increases by 0.069%, 0.372% and 0.183%, which are better results compared to Scenario 1, reflecting the active role in promoting food production of potential land input. As expected, the domestic supply of paddy rice and wheat increases though there is higher gap between export price and producer price, owing to larger production increase. Conversely, a greater reduction in domestic supply of corn occurs under Scenario 2 due to the small output growth and the temptation of export price.

4.2.3. Food consumption

An increase in rural household food consumption can be seen from Fig. 6, because the income growth is higher than price rise, and furthermore, potential land input reinforces this trend under Scenario 2. However, food consumption of urban household declines in response to food price rise and reduced income. In the case of potential land supply, urban household increase the consumption of rice and wheat by 0.231% and 1.212% compared with the baseline. Simultaneously, the reduction in corn consumption is slighter in Scenario 2 than in Scenario 1. For imports and exports, an increase in fuel ethanol production with cassava and sweet sorghum causes a boom in export and reduces imports of food in Scenario 1 and Scenario 2, indicating the role of non-grain fuel ethanol in reducing food dependence on foreign trade.

At the regional rural household level, the largest increase in food consumption occurs in Jilin province and Henan province due to the largest income increase (Fig. 7–9). As expected in Scenario 1, rural households’ consumption on rice, wheat and corn increases by 0.310%−0.401%, 0.443%−0.534% and 0.333%−0.418%, respectively, in the major production areas of sweet sorghum and cassava, including Inner-Mongolia, Guangxi, Jiangxi and Hainan. A more positive story emerges when potential land supply can be realized, shown in Scenario 2.

5. Conclusion and policy implications

This study examines the impacts of expanding fuel ethanol production from sweet sorghum and cassava on food security, which is indicated by food price, supply and consumption. The results suggest an increase in fuel ethanol production will result in a reduction in domestic supply of food without potential land input. However, the positive effects on food price reduction, food supply increase and food consumption rise are obvious under Scenario 2 in which land supply increases. In the case of potential land supply, though the rise in food price ranges from 1.725% to 1.855%, an increase in food consumption mostly happens in both rural household and urban household due to higher income rise. Additionally, domestic output and exports of food go up while imports go down when potential land input to ethanol feedstocks, indicating stability of domestic food supply can be achieved under the condition of regulating food exports.

The above analysis suggests that expanding cassava and sweet sorghum based fuel ethanol can ensure food security in China to a great extent. However, the judge for food security depends on the following three conditions: adequate and quality potential land supply, higher growth in household income than in food price, and reasonable adjustment to the amount and variety of food exports.
Given the contribution of potential land to food security, substantial financial implications will be needed for land reclamation. The cost to reclaim potential land will be very high because most potential land lies in remote and mountainous locations and is short of water resource.

In order to guarantee the stability of access to food, price rise should be properly controlled and household income should be constantly improved. When income growth cannot resist the negative effects of price rise, the government should provide subsidy to the household to indirectly enhance the household consumption capacity.

Under the hypothesis of economic man in the model, the producer aims at maximum profit, and thus, increases exports and decreases domestic supply due to price advantage in foreign market. Therefore, in reality, the government can ensure domestic food supply by properly regulating the variety and quantity of food exports.

Notes
1. Wheat is also used for fuel ethanol production in Henan Tianguan Group Co. Ltd, one of the fuel ethanol producers in China.
2. Food mainly indicates food grains, including rice, wheat and corn in this study.
3. Non-grain crops, a special term used by the Chinese government to describe all crops and plants except rice, wheat and corn, consist of cassava, sweet potato, sweet sorghum and sugarcane at the current stage.
4. In Hainan province and Henan province, corn consumption of rural household is not large.

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References


