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Biofuels and the Greater Mekong Subregion: Assessing the impact on prices, production and trade

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A B S T R A C T

Similar to many other countries, all nations in the Greater Mekong Subregion (GMS) have planned or are planning to develop strong national biofuel programs. The overall goal of this paper is to better understand the impacts of global and regional biofuels on agriculture and the rest of the economy, with a specific focus on the GMS. Based on a modified multi-country, multi-sector computable general equilibrium model, this study reveals that global biofuel development will significantly increase agricultural prices and production and change trade in agricultural commodities in the GMS and the rest of world. While biofuel in the GMS will have little impacts on global prices, it will have significant effects on domestic agricultural production, land use, trade, and food security. The results also show that the extent of impacts from biofuel is highly dependent on international oil prices and the degree of substitution between biofuel and gasoline. The findings of this study have important policy implications for the GMS countries and the rest of world.

1. Introduction

Global biofuel production has been growing rapidly. While motivations for the expansion of biofuels are complex and multidimensional, the most important is to improve national energy security. With the demand for fossil fuels growing and supplies relatively limited, governments in many energy-short countries are searching for any and all means to increase the amount of energy their nations can produce [12,21]. Governments are also interested in biofuels because they may offer a way that will enable them to increase energy consumption without adding to the amount of CO2 in the atmosphere. Some governments also see biofuels as a means to support the politically powerful—or politically sensitive—farm sector (depending on the country).

While there is potential that biofuel could spur rural development, there are concerns regarding its implications on food security and poverty. Biofuels might facilitate agricultural and rural development by fostering greater investment in agriculture and creating jobs in feedstock production, biofuel manufacture, and the transport and distribution of feedstock and products [30,13]. But concerns about its potential effects on food security and poverty are rising [12,19,24]. If world food prices or demand for crops used as biofuel feedstocks experience significant increases, then the age-old concerns of governments and development practitioners regarding food security and poverty may re-emerge as real issues for the first time in decades.

Similar to many other countries, all nations in the Greater Mekong Subregion (GMS)[1] have planned or are planning to develop strong national biofuel programs. The degree of biofuel development greatly differs across countries, but recently every country has proposed a large biofuel development plan [25]. However, the ability to develop and sustain the rapid expansion of biofuel production has been hindered by the lack of information and understanding of the economics of its market. As observed in the GMS [5], and in other areas as well, no country has thus far been able to launch a domestic biofuels industry without the active support of government beyond its normal regulatory role.

Biofuel development in the GMS must therefore take into account the full spectrum of market and societal values, such as forgone food and other agricultural output, impacts on environmental services, and overall improvements in the well-being of the rural poor. A proper economic analysis is necessary to weigh the upfront social costs and benefits of biofuels and to decide when, where, and

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[1] The GMS covers five countries (Cambodia, Lao PDR, Myanmar, Thailand, and Vietnam) and two provinces (Yunnan and Guangxi provinces) of China. In this study, we limit our study to the five countries and exclude the two provinces of China.

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how to embark on a biofuel program. Economic analysis also may be a valuable tool in reshaping planned or existing programs to maximize their efficiency and their net benefits to society.

This study is one of the first steps in attempting to better understand the impacts of the global and regional biofuels on agriculture and the rest of the economy, with a specific focus on the GMS. More specifically, the analysis aims to provide answers to the following questions: how will the rise in demand for biofuels affect food prices, agricultural production, and trade in the GMS and the rest of world? What are the implications on national food security and land use? Answers to these questions could help shape policy recommendations necessary to ensure the development of economically and socially sound biofuels programs in the countries in the region.

The paper is organized as follows. Section 1 is the introduction. Section 2 provides an overview of global biofuel development as well as new initiatives on biofuel programs in the GMS. Section 3 discusses the methodology and scenarios developed for assessing the effects of biofuel development. The impacts of alternative biofuel development scenarios on world food production and prices, national production, and international trade are presented in Section 4. The last section concludes this study.

2. Emerging biofuel development

2.1. Overview of biofuel production in major countries

Global biofuel production has risen rapidly since the early 2000s (Table 1). Although some countries, like the United States (USA) and Brazil, started their biofuel development programs in the mid-1970s when oil prices reached its highest on record, the expansion of biofuel development programs has accelerated only after 2000. Since 2000, growth of global biofuel production has been stimulated by high levels of government support in many countries, as well as by surges in oil prices until late 2008. Global production of biofuels in 2007 amounted to 53.2 million tons—consisting of 44.2 million tons of bioethanol and 9 million tons of biodiesel (Table 1)—equal to nearly 2% of total global transport fuel consumption in energy terms. The USA and Brazil together accounted for almost three-fourths of the global biofuel supply in 2007. In both countries, ethanol accounts for almost all of total biofuel output, though biodiesel production in the US has also increased substantially in the last 2 years.

In the USA, production of bioethanol, which is derived mainly from maize, has surged in recent years as a result of rising world oil prices, tax incentives, and mandates for ethanol as a gasoline-blending component. The total bioethanol production in the US reached 21.3 million tons in 2007 (Table 1), accounting for 48.2% of the global bioethanol output. The demand for maize as feedstock for ethanol has been rising rapidly, with about one-third of the 2007 maize yields in the US used to produce bioethanol. Also, in 2007, biodiesel production in the US was estimated at about 2.1 million tons (Table 1), using 20% of its total soybean output [22]. The Energy Independence and Security Act passed in 2007 has targeted US biofuel production to reach 7.5 billion gallons in 2012, 30 billion gallons in 2020, and 36 billion gallons in 2022. Maize-based bioethanol and cellulosic bioethanol will be the major biofuels in the future. For example, the Act prescribed that of the total 36 billion gallon biofuel production in 2020, 15 billion gallons will be produced from maize (or 50% of total biofuel production), 10.5 billion gallons will be based on cellulosic technologies (about 34% of total biofuel production), 3.5 billion gallons from other energy crops such as sweet sorghum and sugarcane, and 1 billion gallons of biodiesel.

Brazil was the world‘s largest producer of biofuels until 2006, and became the second largest producer thereafter. Although it was overtaken by the US as the top biofuel producer in 2006, the volume of its production and growth in the future still has significant impacts in the world food market, particularly on sugar. In Brazil, production of bioethanol, based entirely on sugarcane, peaked in the 1980s, and then declined as international oil prices fell; however, production has increased rapidly since the beginning of the century (Table 1). Falling production costs, higher oil prices and the introduction of vehicles that allow switching between ethanol and conventional gasoline have led to this renewed surge in output. Bioethanol production in Brazil in 2007 reached 16.5 million tons (Table 1), accounting for 37.2% of the world's total bioethanol production. The government has targeted bioethanol production for 9.5 billion gallons in 2012 (or 31 million tons), and 11.5 billion gallons in 2016 (or 37.7 million tons). The government also enacted a law establishing biodiesel targets of: 2% by the end of 2007 (800 million liters per year), 5% by 2013 (2 billion liters per year), and 20% by 2020 (12 billion liters per year).

Production of biofuels in the European Union (EU) is also growing rapidly. The bulk of production in the EU is biodiesel. The EU's biodiesel production in 2007 reached 5.7 million tons, accounting for more than 74% of the world's biodiesel output (Table 1). The major feedstock used in the EU is rapeseed. Germany is the leading producer of biodiesel with 3.8 million tons produced during 2007 (or equivalent to 41% of world market share), and followed by the US (20%), France (11%), Italy (7%), and other countries [21]. Recently, the EU set a new target for biofuel production by 2020. A new Directive on Bioenergy, published as a Commission Proposal in early 2008, includes an increased and mandatory target to replace 10% of transport fuels with biofuels by 2020 [21]. The proposal makes a clear reference to second-generation biofuels, which are to represent an important portion of this target share.

Currently, many countries follow the practice of setting indicative targets for biofuel development with strong policy support. To promote biofuel development and ensure the targets being set can be achieved, various support policies have been adopted or consid-

Table 1
Biofuel production in major countries during 1996–2006 (million tons).

	1996	2000	2001	2002	2003	2004	2005	2006	2007
Ethanol: world	16.2	15.0	16.2	18.8	23.7	26.5	35.3	39.8	44.2
USA	3.6	5.3	5.8	7.0	9.2	11.1	12.8	15.9	21.3
EU27	n/a	0.2	0.2	0.4	0.4	0.5	0.8	1.5	1.6
Brazil	12.5	9.2	10.0	10.9	12.8	13.1	13.9	14.7	16.5
China	–	–	–	0.0	0.1	0.2	0.8	1.3	1.4
Diesel: world	0.5	0.8	1.0	1.3	1.6	2.0	3.4	6.6	9.0
USA	n/a	n/a	n/a	n/a	n/a	0.1	0.2	0.8	2.1
EU27	n/a	n/a	0.9	1.1	1.4	1.9	3.2	4.9	5.7

Sources: world data are from US Renewable Fuels Association [29], Earth Policy Institute [10], and BIODIESEL 2020 [3]; USA data are from US Renewable Fuels Association [29] and BIODIESEL 2020 [3]; European Union (EU) data are from beyond petroleum [2] and European Biodiesel Board [11]; Brazil data are from Renewable Fuels Associations [23]. n/a: data not available. –: nearly zero.

ered in major countries. The measures affect various stages in the biofuel production-use chain, including agricultural feedstock or biomass production, feedstock or biomass conversion, biofuel distribution, marketing, and final consumption. Given the high production costs of biofuels compared to fossil-based alternatives and the need to modify existing logistics covering infrastructure, transport, and delivery equipment, biofuels are generally regarded as not economically viable. Hence, in the absence of public support, biofuel programs are unlikely to prosper in most countries (except in Brazil).

2.2. Biofuel development in GMS

Among the five GMS countries included in this study, Thailand is the only country that has commercialized the production of biofuel. Biofuel production is undertaken on a very limited scale in Vietnam and Myanmar, and at an experimental level in Cambodia and the Lao People's Democratic Republic (Lao PDR) [25]. The production of bioethanol in Thailand is dependent on two major raw materials: molasses and cassava. At present, most ethanol plants use molasses to produce ethanol [20].

Although all five countries in the GMS are interested in developing biofuels, only Thailand and Vietnam have set clear targets for future biofuel development and provided supportive policies. Myanmar plans to plant *Jatropha* on 2.3 million ha in 2009 for biodiesel production, but no mid-and long-term targets for biofuel development has been set yet [28]. Cambodia and the Lao PDR have not established any specific targets.

Thailand has initiated a large biofuel program. Most ethanol plants produce ethanol from molasses, with the exception of the Thai Nguan Plant that produces 130,000 l of ethanol (about 112 tons) a day from cassava feedstocks. Nine ethanol plants are currently in operation, with a combined capacity of 1.26 million liters a day. The actual production, however, is about 0.98 million liters a day [8]. By the end of 2008, more bioethanol plants will start to operate, and the feedstock demand will gradually shift to cassava. The government encouraged to use bioethanol to substitute for methyl tert-butyl ether (MTBE) and also to use E20 gasoline [8]. It is projected that by 2011, the annual demand for, or production of, bioethanol in Thailand will reach 710,000 tons. For biodiesel, the only crop used is oil palm. The government has mandated the use of B2 (diesel blended with 2% of biodiesel) from 2008. By 2011, B2 will be replaced by B5 and biodiesel production is estimated to reach 890,000 tons [8].

Vietnam is at the initial stage of biofuel development. The nation has made plans for developing three types of biofuels in the future. These are bioethanol from starch and molasses, biodiesel from animal fat and plant oil, and biogas from animal waste. Bioethanol and biodiesel are given greater attention because of their potential for commercial production that could help spur further growth in the economy. According to Decision 177/QD-TTg of the Vietnamese Government, biofuel will account for 1% of the total fuel demand in the transportation sector in 2015 (estimated at 0.25 million tons), and about 5% in 2025 (about 1.8 million tons) [7]. In terms of biofuel production, biodiesel is targeted at 0.15 million tons and 1.2 million tons in 2015 and 2025, respectively. For bioethanol, the target is less than that for biodiesel at about 0.1 million tons in 2015 and 0.6 million tons in 2025 [7]. Jatropha and catfish oil are likely to be the major feedstock for biodiesel production in Vietnam, and sugarcane for bioethanol. Sweet sorghum will make up about 10% of bioethanol feedstocks [7].

Anhydrous ethanol based on sugarcane has been produced at a limited commercial level in Myanmar. One production plant is located in Maunggone, Sagaing Division, and yields 36,000 tons of bioethanol per year. The Myanmar Economic Corporation, a military-based commercial entity, established two large bioethanol plants with a total capacity of 1.8 million gallons of anhydrous ethanol per year [5]. Commercial production, distribution, and utilization began in April 2008. One large private company, the Great Wall has nearly completed the establishment of an anhydrous alcohol processing plant yielding 3700 gallons per day. Another new factory will be constructed by the associate company of the Great Wall in Katha township. Aside from sugarcane, the other crops with potential for bioethanol production in Myanmar are maize, cassava, and sweet sorghum. Biodiesel production is on a pilot project level. The country plans to cultivate jatropha to fulfill future energy requirements. *Jatropha* has been planted since 2006. In a recent plan by the government, the area for jatropha cultivation will reach 3.23 million ha in 2010, up from 2.53 million ha in 2007 [28].

Biofuel production in Cambodia and the Lao PDR is still on a pilot project basis or in an experimental stage. Because food security in the two countries remains of primary concern, both are still very cautious regarding biofuel development. Recently in Cambodia, a village-level biofuel project in Kompong Chang at the center of the country provided small oil expellers for *Jathropa* seeds. The project, which was funded by the Government of Canada, ended in 2006 but is being continued by a private company. Training and dissemination of the technology used in the project are now conducted by various nongovernment organizations (NGOs), academics, and private enterprises. In the Lao PDR, although the government recognizes biofuels as a priority focus area, only KOLAO, the largest agriculture company in the country actively produces biofuels, primarily from *Jathropa.*

3. Methodology and scenarios

While there have been trends of biofuel development emerging in many countries, including those in the GMS, there is little quantitative assessment of the impacts of global and regional biofuel development on agriculture and food self-sufficiency. This section presents the methodology and scenarios used in this study to assess the likely implications of global and GMS regional biofuels for agriculture and the rest of the economy.

3.1. Methodology

For an initial understanding of the likely impacts of biofuel development on agriculture and the rest of the economy, we have built an analytical framework based on the Global Trade Analysis Project (GTAP) platform.[2] As the GTAP model allows multi-features (i.e., multiple commodities and multiple countries), it is possible to model the linkages among biofuels production, energy, and global agricultural markets. Since it is a global trade model, one can track the impacts from world markets into specific countries or region, including the GMS and China.

To make the standard GTAP modeling platform more suitable for this analysis, several modifications were made.[3] First, because the GTAP database does not have a biofuels sector, the production activities that produce biofuels were created and added into the model as a separate sector. Second, agriculture is linked with the energy markets through the biofuel sectors. The parameters that allow for the substitution between capital and energy (that are embodied in GTAP-E (Energy) model) were updated.[4] A set of parameters was added to capture the substitution between biofuels and gasoline.

[2] GTAP is a well-known multi-country, multi-sector computable general equilibrium model [15]. The model is based on the assumptions that producers minimize their production costs and consumers maximize their utilities subject to a set of certain common constraints.

[3] The modelling part of this study is mainly funded by the Bill and Melinda Gates Foundation.

[4] GTAP-E model introduces energy-capital substitution to the standard GTAP model and is widely used for analyzing the policy on energy and climate change.

Third, we also made efforts to refine and determine elasticities of substitution in land allocation among different crops—those that produce biofuels (e.g., maize) and those that do not (e.g., cotton).

3.2. Introducing biofuels into the GTAP database

Version 6 of the GTAP database is used in this study. The standard GTAP database has 57 sectors. Of that total number of industrial sectors, 20 represent the agricultural and processed food sectors. Despite this level of disaggregation, many of the biofuel feedstock crops are aggregated with non-feedstock crops. There is additionally no biofuels industry sector.

The model for this study modifies the standard database in two ways. First, the key biofuel feedstock crops were disaggregated and explicitly included in the model's database. Using trade data from UNCOMTRADE and production data from the Food and Agriculture Organization (FAO), maize was disaggregated from cereal grains (gro), soybeans from oilseeds (osd) and cassava from vegetable and fruits (v_f). A "splitting" program (SplitCom) developed by Horridge [17] was used to perform the disaggregation. Second, new production activities were built into the model to include four biofuel industry sectors, namely sugar ethanol, corn ethanol, soybean diesel, and rapeseed diesel. They were introduced into the GTAP database using a method similar to that developed by Taheripour et al. [26].[5]

3.3. Linkage between agriculture and energy markets through biofuel sectors

To capture the effects of the emergence of biofuel production, the standard GTAP model was extended by introducing energy-capital substitution relationships that are described in the GTAP-E model [6]. In addition to the standard assumptions, substitution between biofuels and petroleum products are accounted for. To introduce the possible substitution of biofuels and petroleum products, a nested CES function between biofuels (bioethanol and biodiesel) and petroleum products was incorporated into the GTAP-E capital-energy commodity nested structure. Such a method was carried out in a way that is similar to the approaches taken by others who also add this sector to the GTAP-E model (e.g., [4,16]. The elasticity of substitution between crude oil and biofuels is crucial in this research since it is a key element that ties the price of energy to the price of food. Interestingly, in past researches on biofuels in the USA, EU, and Brazil, almost all values of the elasticity of substitution are similar to those used by Hertel et al. [16], who set their substitution parameters at 3.0, 2.75, and 1.0 for the USA, EU, and Brazil, respectively. This study used the default value of 2.0, the value of the parameter that is used in Birur et al. [4].

3.4. Allocation of agricultural land

The biofuels boom (especially, the first-generation biofuels) will increase the demand for feedstock crops. However, the feasibility of changing land use from one crop to another may differ significantly by type of land. The standard version of GTAP allocates land using a constant elasticity of transformation (CET) structure. While this feasibility assumes that different types of land use are imperfect substitutes for each other, all uses have the same degree of substitutability. This land-use structure makes it difficult to capture differences in substitutability that will almost surely emerge with the rapid expansion of feedstock crops.

To overcome this problem, different types of new land-use modules are being incorporated into the standard GTAP model. In this study, the approach of Banse et al. [1] in modeling the land-use structure is used. This approach helps capture the different degrees of substitutability between agricultural land uses. The land use allocation structure is created by adding a three-level CET nested structure to the standard GTAP model, which takes into account the different degrees of substitutability among different land use types [18]. Unlike the Banse study, however, no endogenous adjustment of total land supply is allowed as there was not enough information on the availability of new land for agricultural production and the impacts of land and agricultural prices on land supply. In other words, by assumption, while we allow substitutability among crops on the existing stock of cultivated land, there is no allowance for increasing cultivated land. This is a weakness of the model. However, with the exception of Banse, the major economic studies using general equilibrium models (including [16,9,27] make the same assumption about cultivated land being fixed. Because of this, of course, we know that to the extent that new cultivated area will be able to contribute to meeting the targets for biofuels production, the price effect that we generate in the model will be overstated.

[5] In this version of the model, we do not account for dry distillers grains (DDG).

Table 2
Biofuel Production in the Base Year (2006) and Targeted Production in 2020 in Major Countries/Regions in Different scenarios.

	2006	2020		
		Reference (RS)	Scenario 1 (3 producers: USA + EU + Brazil)	Scenario 2: (3 producers + GMS)
Ethanol (million tons)				
USA	15.9	15.9	117.8	117.8
EU	1.5	1.5	21.0	21.0
Brazil	14.7	14.7	43.2	43.2
GMS	0.5	0.5		5.3
Diesel (million tons)				
USA	0.8	0.8	6.9	6.9
EU	4.9	4.9	46.4	46.4

Note: Data for production in 2006 are actual numbers, and data in 2020 in the last column are governments' targeted levels based on the discussions in Section 2 of this paper. (For more information on the biofuel development in GMS, refer to the ABD report titled "Strategies and Options for Integrating Biofuel and Rural Renewable Energy Production into Rural Agriculture for Poverty Reduction in the GMS".) EU = European Union; GMS-5 = Cambodia, Lao PDR, Myanmar, Thailand, and Vietnam; USA = United States of America.

3.5. Formulation of scenarios

As stated earlier, the main aim of this study is to assess the impacts of global and regional biofuel development on the GMS. In this light, four scenarios were developed—one reference scenario and three alternative scenarios. The first two alternative scenarios simulate the possible effects of fulfilling the targets in: (i) other regions, i.e., USA, EU25, and Brazil (scenario 1 [S1]); and (ii) five GMS countries. The third alternative scenario assesses the effects of global biofuel development that are determined by market mechanisms under the assumptions of high biofuel–gasoline substitution elasticity and high oil prices (H–H scenario). The counterpart is the reference scenario, which is constructed under the assumption that biofuel production in the world do not expand beyond its production level in 2006. In other words, in the reference scenario, there is no emergence of biofuels in the future.

In the first two alternative scenarios, we relax the assumption about the static nature of biofuel production in the reference scenario. Biofuel production will meet the target level of individual countries as shown in Table 2. The difference between these two alternative scenarios is that different countries are taken into account. Only the three most important biofuel-producing countries/regions (i.e., USA, EU25, and Brazil) are considered in the first scenario (S1). In the second scenario (S2), data on biofuel development in the five GMS countries are added to S1 (Table 2).

To meet the target level, the price subsidy to the biofuel industry is endogenously determined. In other words, in the modeling work, when the market solution for biofuel production (i.e., the solution without the exogenous target implemented) is less than the volume of biofuel production mandated by policy, we will continue to raise the price subsidy for the production of biofuels until the target is exactly fulfilled. While there may theoretically be other ways that governments could try to induce biofuel industrial entrepreneurs to meet the policy-set levels (e.g., through tax concessions or direct fiat), in most countries in the GMS, biofuels price subsidy is nonetheless the main instrument.

Because biofuel development might be affected significantly by world oil prices, and also by the extent of substitution between biofuel and gasoline, the third alternative scenario (H–H) was also formulated. This scenario is constructed to assess the possible impacts by market determination under the assumptions of high biofuel–gasoline substitute elasticity and high world oil prices. In this scenario, oil prices are allowed to rise to a level of about US$120 per barrel, a level that was reached in mid-2008. The elasticity between biofuel and gasoline adopted is 20, which indicates flexible usage of gasoline and biofuel by vehicles [14]. We also assume that only first-generation biofuel production technology is adopted during the period 2006–2020. Although second-generation technology is being developed, it is not incorporated in the analysis due to lack of information and the current unfeasibility for economic reasons.

Currently, there is almost no empirically-based research (that we know of) seeking to estimate the elasticity of substitution between biofuel and gasoline. Based on the historical simulation between 2001 and 2006 [16], the calibrated elasticities of substitution between biofuel and gasoline in the USA, EU and Brazil are between 1.0 and 3.0. Intuitively, these levels of elasticities imply that there is little substitutability between biofuels and gasoline. Since the estimates are based on data from a period when policy mandates are trying to influence an increase in biofuel production by requiring transportation fuel blenders to use biofuels, the demand for biofuels will move up with the demand for gasoline. Such a finding implies that there is little flexibility among vehicle fleet of shifting between biofuels and traditional fossil fuels.

Unfortunately, there are no estimates of elasticity of substitution in the future. As a result, many authors (e.g., [16] have used the low elasticity values described above. However, in the case of biofuels, it is unclear whether future elasticities will be similar to values in the past. If vehicles become more flexible in their use of fuels (that is, either biofuels or gasoline) and if needed infrastructures are developed to facilitate distribution of biofuels, then biofuels and traditional fossil fuels could become more substitutable in the future. In fact, there are many actions by governments (e.g., mandating flexible-fuels vehicles) that would likely cause the elasticity of substitution to rise. For this reason, we adopt the value of 20 for the elasticity of substitution in one of the alternative scenarios developed in this paper, implying that vehicle owners are able to choose relatively freely between biofuels and gasoline.

4. Results of the impacts

4.1. Impacts on world prices

Biofuel development in the USA, EU, and Brazil (S1) will have a remarkable impact on world food prices. Prices of all agricultural commodities will increase with great variations. Compared with the reference scenarion, the world average export prices of maize, soybean, other oilseeds, and sugar under S1 will rise by 17.7%, 13.6%, 27.6%, and 11.3%, respectively, in 2020 (Table 3, column 1).

In the land-use structure, it is assumed that the land-use mobility of wheat, other grains, cotton, and other crops with feedstock commodities is higher than that of rice, vegetables, and animal pastures. As a result, the prices of wheat, other grains, fibers (mainly cotton), and other crops also increase significantly by 7.5%, 7.9%, 7.7%, and 11.1%, respectively, (Table 3, column 1).

Table 3
Impacts on world average export price of agricultural commodities, compared with the reference scenario (%) in 2020.

Commodity	Scenario 1: (3 producers: USA + EU + Brazil)	Scenario 2: (3 producers + GMS-5)	Scenario 3: (high oil price and + high substitution)
Rice	4.1	4.5	8.2
Wheat	7.5	7.6	23.5
Maize	17.7	17.8	64.2
Other grains	7.9	7.9	20.8
Cassava	5.5	6.6	74.9
Vegetables and fruits	5.5	5.6	10.6
Soybean	13.6	13.8	45.8
Other oilseeds	27.6	27.8	38.1
Sugarcane	11.3	12.2	32.9
Fibers	7.7	7.8	22.4
Other crops	11.1	11.3	22.9
Beef and mutton	2.5	2.5	6.9
Pork and poultry	2.6	2.7	6.1
Milk	0.7	0.8	2.9
Processed food	1.2	1.2	4.0

The results also indicate that there are modest increases in the prices of other crops that have less land-use mobility with feedstock crops. These include rice, and vegetables and fruits, with price increases of only 4.1% and 5.5% in 2020 (Table 3, column 1).

The prices of processed food and animal products will also increase mainly due to the rising cost of ingredient inputs (e.g., maize and other feeds). Therefore, the prices of these commodities increase relatively less than that of crops. As shown in column 1 of Table 5, the prices of beef and mutton, pork and poultry, dairy products, and processed food will increase by 2–3%.

The impacts of GMS countries' biofuel development on world prices are measured by the difference between S2 (column 2) and S1 (column 1) in Table 3. The results show that the impacts of biofuel development in the GMS on the world prices of agricultural commodities, except cassava and sugar, are very minimal. For example, the world prices of cassava and sugar in S2 rise by 1.1% and 0.9%, respectively, in 2020. The reasons for this are twofold. First, and most importantly, the policy-mandated target volumes in the GMS nations are much less than those in the USA, EU and Brazil. As shown in the Table 2, it is expected that about 5.3 million tons of ethanol will be produced in 2020 in the GMS regions. While this level is much higher than the volume of ethanol being produced presently in the GMS region, it only accounts for 4.5% of the expected volume of production in the USA, 25.2% of that in the EU, and 12.3% of that in Brazil. Second, the feedstock used for ethanol production will come mainly from cassava, sugar and other coarse grains (e.g., sweet sorghum). Of this group of crops, it is expected that cassava will take the largest share. Since cassava (as well as sweet sorghum) is almost always used domestically and is not highly traded, the development of bioethanol in the GMS countries will create an impact mostly inside the region (and not on the international markets). According to FAO data, between 2001 and 2006, the share of cassava production that moved through international trade was less than 0.1%.

4.2. Impacts on world agricultural production

With price changes due to the global biofuel development, world agricultural production will change significantly. The production of feedstock crops will increase considerably at the

Table 4
Impacts on world agricultural production in scenario 1 (three producers: USA + EU + Brazil), compared with the reference scenario (%) in 2020.

Commodity	Scenario 1:(3 producers: USA + EU + Brazil)							Scenario 3:(H–H)
	USA	EU27	Brazil	China	GMS	Rest of world	World total	World total
Rice	−13.6	−1.2	−7.0	−0.2	−0.5	−1.8	−1.4	−5.7
Wheat	−14.5	−16.9	−6.8	−0.5	−0.8	4.2	−0.4	−12.6
Maize	59.4	−12.5	−6.3	18.0	14.3	28.6	27.8	95.4
Other grains	−13.9	−9.4	−5.1	−5.2	−3.0	5.1	−0.6	4.6
Cassava	−12.5	−13.9	−1.1	−3.9	−0.9	−1.0	−0.9	14.3
Vegetables and fruits	−5.2	−8.1	−1.7	−0.2	−0.5	0.3	−1.0	−3.5
Soybean	−5.3	−21.4	6.1	14.3	10.9	10.9	1.5	18.5
Other oilseeds	89.4	219.5	180.1	71.4	12.1	30.0	60.8	73.1
Sugarcane	11.2	−1.1	64.6	5.4	3.2	0.7	8.1	21.0
Fibers	−13.5	−37.6	−6.7	4.8	6.0	4.6	−0.9	−8.3
Other crops	−8.3	−11.5	−2.7	−6.7	6.7	4.9	−0.9	−7.7
Beef and mutton	−1.5	−0.4	−4.0	−0.2	−0.2	−0.3	−1.0	−3.4
Pork and poultry	0.0	-2.9	−3.1	−0.8	−0.1	−0.5	−1.1	−5.5
Milk	−1.4	0.1	−0.2	−0.8	−0.5	−0.6	−0.6	−3.4
Processed food	−0.5	−1.4	−2.4	−0.7	−0.7	−0.5	−0.8	−3.0

Table 5
Impacts on supply of agricultural commodities in world and GMS, compared with the reference scenario (%) in 2020.

Commodity	World			GMS 5 countries		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
Rice	−1.4	−1.5	−5.7	−0.5	−2.7	−7.6
Wheat	−0.4	−0.4	−2.6	−0.8	−1.9	−1.3
Maize	27.8	27.8	95.4	14.3	10.4	28.7
Other grains	−0.6	−0.6	−4.6	−3.0	−4.6	−3.3
Cassava	−0.9	3.2	9.3	−0.9	47.4	103.6
Vegetables and fruits	−1.0	−1.0	−3.5	−0.5	−2.6	−7.6
Soybean	1.5	1.5	18.5	10.9	6.9	25.2
Other oilseeds	60.8	60.8	43.1	12.1	8.3	−2.8
Sugarcane	8.1	8.9	21.0	3.2	30.8	50.5
Fibers	−0.9	−0.9	−4.3	6.0	1.5	−2.4
Other crops	−0.9	−0.9	−2.7	6.7	2.8	0.1
Beef and mutton	−1.0	−1.0	−3.4	−0.2	−0.5	−2.4
Pork and poultry	−1.1	−1.0	−5.5	−0.1	−1.2	−4.4
Milk	−0.6	−0.6	−3.4	−0.5	−0.7	−1.9
Processed food	−0.8	−0.8	−3.0	−0.7	−3.0	−8.4

expense of other agricultural commodities (Table 4). For example, in the USA, the production of maize, other oilseeds, and sugar under S1 will increase by 59.4%, 89.4%, and 11.2%, respectively, compared with the reference scenario in 2020. In contrast, production of many other crops, animal products, and processed food will decrease, especially among crops with higher mobility of land-use for feedstock crops. The production of wheat, other grains, cotton, and other crops will drop by 14.5%, 13.9%, 13.5%, and 8.3%, respectively (Table 4, column 1). Similar adjustments are also projected in the EU (column 2) and Brazil (column 3).

The production of feedstock commodities will increase moderately even in regions without biofuel expansion in S1 (e.g., China and the other five GMS countries). As shown in Table 4, the production of maize, soybean, other oilseeds, and sugar will increase, respectively, by 18.0%, 14.3%, 71.4% and 5.4% in China, and by 14.3%, 10.9%, 12.1% and 3.2% in the five GMS countries (Table 4), compared with the reference scenario in 2020. The reduction in production of other agricultural commodities in China and the GMS countries is however less than that in the USA, EU, and Brazil. This mainly results from the large drop in production in the USA, EU, and Brazil, which will create opportunity for other countries to produce more.

Similar to the effects on world prices, the impacts of biofuel development on world agricultural supplies in the GMS are very limited and only concentrated to those feedstock crops used in the GMS countries. Under S2, compared with biofuel development in the USA, EU, and Brazil (S1), more production resources will be allocated to produce the feedstock crops used by GMS countries (Table 5). Therefore, the production of agricultural commodities not used as feedstock in the region will be reduced. However, such diversion effects are small. Compared with S1, the world production of cassava and sugar will increase by 4.1% and 0.8%, respectively (the difference between S2 and S1 in Table 5).

If the target levels in different regions are fulfilled in 2020, the subsidies will be quite high under the assumptions of a relatively low price of petroleum in 2020 and a low elasticity of substitution between gasoline and biofuel. According to the simulation results, we calculate the subsidy rates[6] in the USA, EU, Brazil and GMS to be 54.0%, 72.8%, 23.3% and 48.8%, respectively. Such results indicate that under the scenario of a relatively low price of petroleum in 2020 and a low elasticity of substitution between gasoline and biofuel, governments need to pay high subsidy rates to biofuel producers in order to meet their targets. However, our results also show that there are considerable differences in the subsidy rates that must be paid. For example, the subsidy rate in Brazil is the lowest, whereas it is highest in the EU.

[6] The subsidy rate is calculated by using the ratios between the total subsidy paid to biofuel industry and the market value of the biofuel production.

Table 6
Impacts on price of agricultural commodities in GMS countries, compared with the reference scenario (%) in 2020.

Commodity	Scenario 1: (three producers: USA + EU + Brazil)	Scenario 2: (three producers + GMS)	Scenario 3: (H–H)
Rice	3.8	6.5	6.1
Wheat	8.9	9.6	20.9
Maize	11.1	12.5	37.7
Other grains	5.1	6.4	15.2
Cassava	4.2	21.7	99.6
Vegetables and fruits	4.0	6.9	18.0
Soybean	10.3	11.1	32.8
Other oilseeds	12.4	14.1	20.7
Sugarcane	4.8	27.6	63.6
Fibers	8.1	9.1	19.3
Other crops	8.6	9.9	22.1
Beef and mutton	0.6	1.4	2.2
Pork and poultry	1.7	3.0	5.0
Milk	0.2	0.4	2.5
Processed food	1.5	3.1	8.2

4.3. Impacts on agricultural prices in GMS countries

Biofuel development in the USA, EU, and Brazil will significantly increase agricultural prices in the GMS countries. Although it is assumed that there is no further biofuel development in the GMS in S1, the rising world prices will still affect the GMS countries through international trade. Table 6 shows that the supply price of all agricultural commodities in the GMS countries will increase, especially for those commodities used as feedstock in the USA, EU, and Brazil. The prices of maize, soybean, other oilseeds, and sugar will rise by 11.1%, 10.3%, 12.4%, and 4.8%, respectively, in 2020. Meanwhile, the prices of commodities that have high mobility of land usage by feedstock crops and are highly dependent on the world market to satisfy domestic demand in the GMS will also increase significantly. For example, the prices of wheat and fibers[7] will rise by 8.9% and 8.1%, respectively.

Biofuel development in the GMS countries will also have some impacts on agricultural prices, but the effects are concentrated on several feedstock commodities. This is because future biofuel development in those countries is mainly based on two commodities: cassava and sugarcane. If the targeted biofuel production is realized in 2020, the domestic prices of these two commodities will increase significantly. As shown in column 2 of Table 6, the prices of cassava and sugarcane will rise by 21.7% and 27.6%, respectively, as compared with the reference scenario. Meanwhile, as more resources are shifted to produce these two commodities, the prices of other commodities in the GMS countries will increase further compared with those in S1.

Interestingly, compared with that in S1, biofuel development in the GMS countries has much less effect on many other agricultural commodities. For example, the prices of wheat, maize, other grains, soybean, other oilseeds, fibers, and other crops rise by 0.7%, 1.4%, 1.3%, 0.8%, 1.7%, 1.0%, and 1.3%, respectively, in 2020 (difference between S2 and S1 in Table 6). These rates are much smaller than the increases driven by biofuel development in the USA, EU, and Brazil. By relative changing term (the change in price in S2 divided by the correspondence in S1), however, there are significant impacts on rice, vegetables and fruits, pork and poultry, and processed food compared with S1. There are two main reasons for this. First, biofuel development in S1 has fewer effects on these commodities because of the low mobility of land-use between other crops and feedstock crops. Second, these four commodities (i.e., rice, vegetables and fruits, pork and poultry, and processed food) are very important in the GMS countries—their share constitutes 74.9% of the total agricultural production in those countries.[8] Therefore, biofuel development in the GMS countries will have more remarkable effects on those commodities. However, the absolute change in price is small. For example, the prices of rice, vegetables and fruits, pork and poultry, and processed food increase by 2.7%, 2.9%, 1.3%, and 1.6%, respectively, compared with those in S1.

4.4. Impacts on agricultural production and land use in GMS

In response to the price changes, the production structure and land use by different agricultural commodities will also change significantly in the GMS countries. The production of feedstock crops, which are also used as feedstocks in the USA, EU, and Brazil, will increase in the GMS countries. According to the simulation, production of maize, soybean, other oilseeds, and sugarcane will increase by 14.3%, 10.9%, 12.1% and 3.2%, respectively (Table 5, column 4). Interestingly, production of fiber and other crops (mainly horticultural commodities, coffee, etc.) will rise by about 6.0–6.7%. All other agricultural commodities only increase or decrease slightly.

However, the story is different with regard to the impacts on cotton and other crops. Cotton (or fibers) is heavily dependent on the world market to satisfy the domestic demand of the GMS countries. Self-sufficiency of cotton in the five GMS countries in 2001 was only 24%, and this rate will be further reduced to 16% in 2020, according to the reference scenario simulation. When the world supply of cotton drops due to the biofuel boom in the USA, EU, and Brazil, the demand will shift to domestic supply and domestic cotton production will increase in the GMS countries. On the other hand, export of other crops (mainly horticulture) in GMS countries will rise significantly due to the projected decline in horticulture supply in the rest of the world.

While biofuel expansion in the GMS will have less effect on the world prices and production, it will significantly change agricultural production within the region. Compared with that in S1, the production of cassava and sugar, which are used as feedstock in the GMS countries, will rise remarkably by 48.3% (from −0.9% in S1 to 47.4% in S2) and 27.6% (from 3.2% in S1 to 30.8% in S2, columns 4 and 5, Table 5), respectively. As more resources are converted to these two biofuel feedstock crops, the output of other agricultural commodities will decline slightly in S2 compared with that in S1 (Table 5, columns 4 and 5).

4.5. Impacts on agricultural trade in the GMS

It is interesting to note that biofuel development in the rest of world will increase the trade surplus in the GMS. For example, in S1 (biofuel development in the USA, EU, and Brazil), the exports of all agricultural commodities, except processed food, will increase in the GMS countries (Table 7, column 1). In contrast, imports will decrease. Such a shifting trend is mainly caused by the higher world market prices and the relative lower domestic prices. The extent of the increase in exports of one commodity depends on both its trade status and opportunity created by biofuel development in the rest of world. For example, with the strong comparative advantage of producing horticultural crops in the GMS and the high world prices (rising by 11.1% in Table 3) caused by biofuel

[7] Self-sufficiency in wheat and fiber in five GMS countries is only 0.6% and 24.4% in 2001 according to the GTAP 6 database. According to our prediction, self-sufficiency in fiber in five GMS countries will further be reduced to 14.9% in 2020. There is high dependence on the world market to meet the domestic demand for the two commodities.

[8] Rice, vegetables and fruits, pork and poultry, processed food in the total agricultural production account for 12.3%, 10.9%, 14.9%, and 36.8%, respectively, in the reference scenario in 2020.

Table 7
Impacts on agricultural trade of GMS, compared with the reference scenario (million US$) in 2020.

Commodity	Export			Import			Net export		
	S1	S2	S3	S1	S2	S3	S1	S2	S3
Rice	3	−1	1	−15	−7	−26	18	6	27
Wheat	0	0	0	−10	−7	−21	10	7	21
Maize	9	6	51	−58	−52	−98	67	58	149
Other grains	1	0	0	−1	0	0	2	0	0
Cassava	30	−116	−429	−2	20	58	32	−136	−487
Vegetables and fruits	52	−14	−218	−13	6	34	65	−20	−252
Soybean	11	8	23	−10	−2	4	21	10	19
Other oilseeds	13	9	−11	−12	−12	−16	25	21	5
Sugarcane	20	−12	−23	−1	6	13	21	−18	−36
Fibers	6	3	−10	−22	−18	−43	28	21	33
Other crops	367	229	218	−35	−26	−55	402	255	273
Beef and mutton	3	2	−1	−6	−3	−23	9	5	22
Pork and poultry	75	9	−19	−15	5	−19	90	4	0
Milk	5	0	−16	−4	−6	−62	9	6	46
Processed food	−139	−204	−1675	9	40	92	−148	−244	−1767

Note: S1, S2 and S3 stand for scenario 1 (only three major biofuel producers, US, Brazil and EU, develop biofuels), scenario 2 (three major biofuel producers plus GMS-5 develop biofuels), and scenario 3 (three major biofuel producers plus GMS-5 and China develop biofuels).

development in the USA, EU, and Brazil, the export of other crops (mainly horticulture) will increase by US$367 million in GMS in 2020 (column 1, Table 7), compared with the reference scenario. However, although world prices of maize, soybean, and oilseeds will rise more than the prices of horticultural crops, the export of those commodities will still be very small as there is less comparative advantage for these commodities in the GMS. As a whole, the net export of agricultural commodities will improve by US$650 million in S1 compared with the reference scenario in 2020.

However, the trade status of those feedstock crops used in the GMS will be reversed in S2. As biofuel development in the GMS will significantly raise the domestic prices for cassava and sugarcane, imports of these two commodities will rise, while exports will decrease significantly. The export of cassava and sugarcane will shift from the high US$30 million and US$20 million, respectively, in S1 to negative US$116 million and negative US$12 million, respectively, in S2. The imports of cassava and sugarcane will be converted from negative US$2 and negative US$1 million, respectively, in S1 to US$20 million and US$6 million, respectively, in S2 (Table 7). As biofuel production in the GMS will increase the production cost of other agricultural commodities, the expansion of exports in S2 will be much smaller than that in S1, and import will also increase more in S2. As a result, the total net export in S2 will decrease by US$25 million compared with the reference scenario.

4.6. Impacts of biofuel developments in the H–H scenario

So far, the discussion has focused on the impacts of biofuel development in two alternative scenarios with assumptions of low oil prices US$60/barrel and low substitution of biofuel for gasoline (3) in 2020. Under these assumptions, substantial subsidies and policy support will be necessary to achieve the targets of biofuel development set by the governments. However, the situation will change a lot if the above assumptions on oil prices and elasticity of substitution between biofuel and gasoline change.

The impacts of biofuel development in the H–H scenario are presented under scenario 3 in Tables 3–8. The key findings from the analysis of this scenario are summarized below.

First, in the H–H scenario, the production of biofuels will be much higher than the targets set by the governments in all countries studied. The simulations project increases of ethanol production in the USA, EU, Brazil and the GMS in 2020, respectively, by 10.4, 24.1, 5.6 and 29.4 times the production in 2006 (Table 8, column 2). Biodiesel production will also increase by 20.4 times in the USA and 13.1 times in the EU over the same period (Table 8, column 2). The growth of biofuel production in each country in the H–H scenario is much larger than any target level set by the different countries in 2020 (Table 8, column 1).

Second, the world prices of agricultural commodities in the H–H scenario will be much higher than in any scenario presented earlier. The world average export prices of maize, soybean, other oilseeds and sugarcane in the H–H scenario will rise by 64.2%, 45.8%, 38.1% and 32.9%, respectively, compared with the reference scenario in 2020 (Table 3, column 2). Meanwhile, the prices of other non-feedstock crops will also rise significantly. The prices of rice, wheat, other grains, vegetables and fruits, cotton and other fibers, and other crops will increase by 8.2%, 23.5%, 20.8%, 10.6%, 22.4% and 22.9%, respectively, in 2020.

Third, the production of most agricultural commodities will also change dramatically. The production of feedstock crops will increase significantly at the expense of other agricultural commodities (Table 5). The global production of maize, soybean, other oilseeds and sugar in the H–H scenario will increase by 95.4%, 18.5%, 73.1% and 21.0%, respectively, compared with the reference scenario in 2020 (Table 4, last column). In contrast, the production of other crops, animal products, and processed food will decrease, especially for those crops with higher mobility of land-use with feedstock corps. Compared with the reference scenario in 2020, the production of wheat, other grains, cotton, and other crops will drop by 5.7%, 12.6%, 8.3%, and 7.7%, respectively, in 2020. With the increasing cost of feeds and intermediate inputs, the production of

Table 8
Percentage changes (%) in biofuel production in 2006–2020 under the planned target and the H–H scenario.

Item	Target	H–H scenario
Ethanol productions		
USA	640	1038
EU27	713	2410
Brazil	193	560
GMS	980	2942
Diesel production		
USA	740	2038
EU27	711	1311

Note: H–H scenario: this scenario assumes that global biofuel development is determined by market mechanisms, and specifically assumues high biofuel–gasoline elasticity and high oil price.

beef and mutton, pork and poultry, dairy products, and processed food will decrease by about 3–6%.

Fourth, in the H–H scenario, agricultural prices in the GMS will also rise significantly. Besides the increasing prices of feedstock used by the USA, EU and Brazil, the prices of feedstock used in the GMS will also rise substantially. The simulations show that the prices of maize, soybean, other oilseeds, other grains, sugarcane and cassava will rise by 37.7%, 32.8%, 20.7%, 15.2%, 63.6%, and 99.6%, respectively (Table 6, column 3). These price increases in the GMS are much higher than those found in S2. Meanwhile, the prices of non-feedstock crops and other animal products in the H–H scenario will also rise much more than those in S2.

5. Concluding remarks

This study reveals that global biofuel development, particularly biofuel programs in the USA, EU, and Brazil, will have significant impacts on world agricultural prices and production. The rise of biofuel development will significantly increase the prices of biofuel feedstock crops such as maize, oil crops, sugar, and cassava. Because of land substitution effects, the prices of other crops will also rise with large variations due to the mobility of land substitution between feedstock crops and non-feedstock crops. In response to price changes, the production of biofuel feedstock crops will increase significantly, while other crops and livestock production will fall moderately in almost all countries, including the GMS.

Increased production of the feedstock crops (e.g., maize, oil crops, and sugarcane) in any GMS country due to biofuel production in the rest of world will raise the supply of these commodities in that country, increase their exports to (or reduce their imports from) the rest of world, as well as raise the national self-sufficiency level of these commodities. These results indicate that while importing countries will have to pay higher prices for their imports of maize, soybean, rapeseeds, edible oils and sugar, domestic production and self-sufficiency of these commodities will also grow, in the long run, with rising global food prices. For exporting countries, the expansion of biofuel in the rest of world will increase their domestic production and exports with higher export prices.

This study also shows that while biofuel development in the GMS will have little impacts on global agricultural prices and production, it will have significant effects on domestic agricultural production and land use. The rapid expansion of domestic biofuel production will substantially increase feedstock production and modestly reduce production of other crops and livestock. Overall, the crop sector will be more intensified. Although environmental issues have not been assessed in this study, it is expected that expansion of feedstock crop may also result in mono-crop systems that could have negative consequences on the environment.

Changes in prices and production in each of the GMS countries due to its own domestic biofuel production will also induce significant changes in its agricultural trade. Overall the agricultural trade deficit (or surplus) will increase (or decline) modestly in each of the GMS country. Therefore, there are some implications on national food self-sufficiency and on trade-offs between food, feed and fuel. While reducing crude oil imports through the national biofuel program can improve national energy security, it may have adverse effects on national food self-sufficiency as the imports (or exports) of food and feed will rise (or fall). It is worth noting that these results hold true when using food or non-food crops for biofuel production in each of the five GMS countries because crops compete for uses of land and other resources.

It is also important to note that the extent of the impacts of biofuel development on the prices, production, and trade of agricultural and food products is highly dependent on two other factors. One is the international oil price, and the other is the degree of substitution between biofuel and gasoline. If energy prices rise to a certain level (e.g., US$120/barrel in this study) in 2020, and if ethanol becomes increasingly substitutable for gasoline, the only policy that ensures food self-sufficiency is to ban biofuels. Even if any country reduces or eliminates its subsidy and other policies supporting biofuel development, those decisions would not matter.

In any case, biofuels are good news for agricultural producers who own land and sell crops in the market. With rising agricultural prices and corresponding rise in land prices and agricultural wages, farmers' incomes and their ability to buy food will improve. In this regard, biofuels may improve their household food security.

Of course, biofuels are bad news to consumers, particularly the poor who are net food purchasers. It is inevitable that many consumers will get hurt. It is thus essential to develop social security systems to provide the necessary support for vulnerable citizens. On the other hand, there will be more responses from both government and the private sector in agricultural investment. Increasing investment in agriculture induced by higher food prices will raise agricultural productivity, which will partly offset the rise in agricultural prices from the expansion of the biofuel industry.

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