Construction of the Malaysian Agricultural and Plantation Greenhouse Gas Equilibrium Model (MAPGEM)

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Cover design by Kenneth Szulczyk

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1 MAPGEM Background

The Malaysian Agricultural and Plantation Greenhouse Gas Equilibrium Model (MAPGEM) is a partial equilibrium model. A partial equilibrium model only contains several markets of an economy. It determines the equilibrium price and quantity for each market while commodities and resources flow between markets. We assume Malaysia is a large producer that influences market prices. The domestic and export inverse demand functions represent the nation at the national level and set the market prices. Malaysians consume agricultural commodities and represent domestic inverse demand functions. Meanwhile, foreigners consume products and commodities via export inverse demand functions. The model treats Malaysia's trading partners as one homogeneous block. A growing population increases the demand for more products and commodities from the agricultural and plantation sectors and raises market prices over time. A growing Malaysian population increases domestic demand while a rising world population consumes more Malaysian exports.

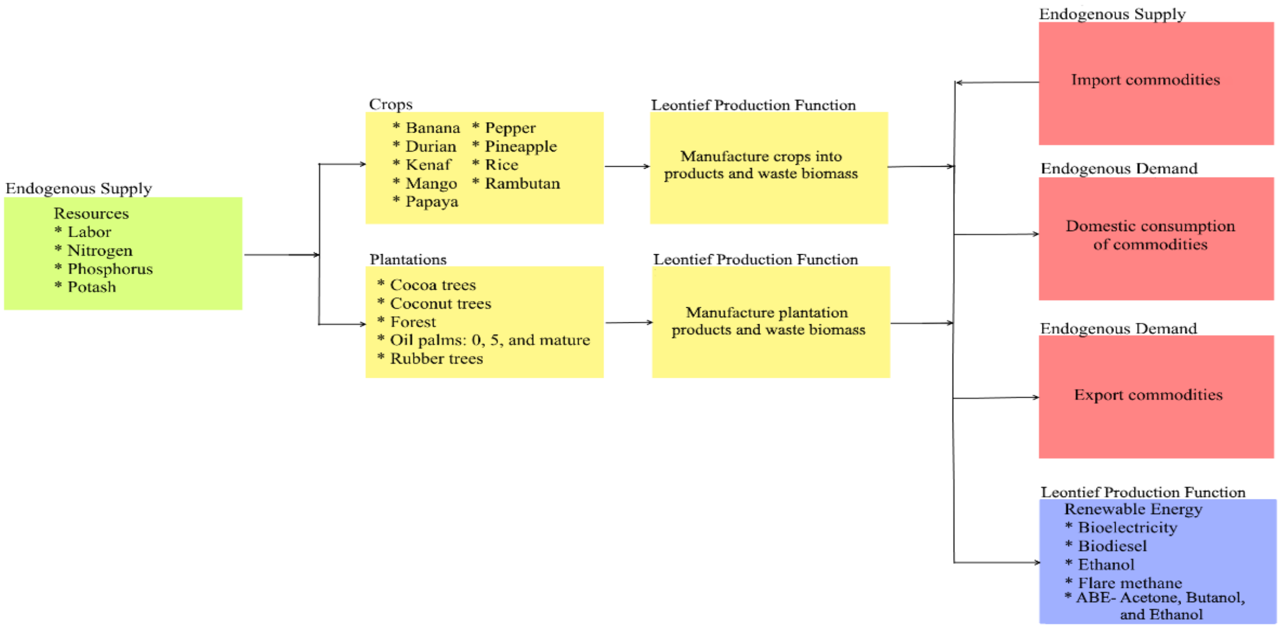
Inverse supply functions include imports because Malaysians import several commodities such as rice. Similar to demand, import supply occurs at the national level. On the other hand, Malaysian farmers and landowners employ labor and apply fertilizer to grow crops and plantation trees on their land. They grow and harvest the crops and trees at the state level because states differ in soil, rainfall, labor productivities, growing costs, and fertilizer requirements. In the model, fertilizer is decomposed into nitrogen, phosphorus, and potash. As Malaysian agriculture expands (contracts), agricultural industries consume more (less) fertilizer, expand (contract) land, and hire more (less) labor, which raises (drops) fertilizer prices, wages, and land value. The model splits crops and plantations into two categories. Plantations have a dynamic relationship because plantation owners convert cocoa, coconut, forest, and rubber in oil palms. On the other hand, crops are more flexible and include banana, durian, kenaf, mango, paddy, papaya, pepper, pineapple, and rambutan.

Figure 1.1 shows the linkages between the components in MAPGEM. Farmers and plantation owners employ resources that start from the left side and move products and commodities to the right. Crops include several trees that rapidly grow and produce fruit within five years. Furthermore, MAPGEM allows producers to switch land use in plantations. landowners can develop new oil palm plantations from coconut, cocoa, rainforest, or rubber. The dynamic nature of plantations allows MAPGEM to load the 2015 tree inventory. On the other hand, producers can grow any combination of crops. However, MAPGEM constrains crop production to match 2015 numbers and lessens the crop constraint over time. Then farmers harvest crops and plantations to manufacture products that Malaysians and foreigners consume via domestic and export demands. Land use and agricultural production are calibrated to replicate the 2015 agricultural statistics from the National government.

Two factors contribute to the dynamic nature of the model. First, MAPGEM incorporates land use changes such as landowners expanding the oil palm plantations at the expense of the other plantation trees. Second, MAPGEM incorporates the population forecasts from Department of Economic and Social Affairs [2015] and allows the inverse demand functions to increase over time along with the population growth.

Figure 1.1 shows three sets of Leontief production functions for the crops, plantations, and renewable energy. Production functions allow producers to produce a variety of commodities from trees, which producers transport to the national domestic consumption and export markets. Furthermore, the crop and plantation production functions include waste biomass. MAPGEM treats waste byproducts such as empty fruit baskets (EFB), oil palm mill effluent (POME), palm fiber, palm shells, and rice straw as standards products. The byproducts have zero market prices, and producers neither export nor import

Figure 1.1: MAPGEM Overview



them. However, producers can take the waste biomass and produce a variety of renewable energies via the Leontief renewable energy production functions. For example, the producers can burn the biomass to generate bioelectricity or utilize lignocellulosic fermentation to convert wastes into ethanol or butanol that is blended with petrol. Furthermore, producers can convert palm oil, palm fatty acid distillates, and yellow grease into biodiesel that substitutes for diesel fuel. Moreover, producers can collect the methane gas that POME emit and flare the gas to reduce the warming potential of greenhouse gases or burn the methane to generate electricity. The producers sell the renewable energy to the consumers at fixed prices in Figure 1.1 since the Malaysian government sets the consumer prices for fossil fuels. At last, renewable energy would generate revenue for the agricultural and plantation industries and also recycles greenhouse gas emissions.

The power of MAPGEM lies in its policy analysis. The examples include:

- MAPGEM predicts market prices and quantities for different government policies from 2020 to 2065 in five-year increments. Consequently, MAPGEM can predict changes in agricultural prices, employment, deforestation, GHG emissions, and land use change if government policies require palm oil mills to supply more renewable energy.
- Researchers can adjust the renewable energy prices to estimate how much renewable energy the agricultural producers could provide.
- Researchers can test a variety of government subsidies. For example, the government pays producers a subsidy for every liter of biodiesel sold or a subsidy for every kilowatt-hour generated from waste biomass.
- MAPGEM can analyze scenarios where the capital and operating costs decrease over time.
- MAPGEM can estimate the impact of minimum fuel mandates, whereas producers must supply a minimum quantity of renewable energy relative to the respective fossil fuel markets. For instance, the researcher can test if the agricultural industries can generate a minimum level of Malaysia's

electricity's need. MAPGEM uses the population forecast to predict energy usage until 2065. In addition, MAPGEM can answer whether the oil palm plantations can replace a minimum level of the country's diesel fuel.

- MAPGEM can simulate a carbon tax or carbon price because MAPGEM accounts for the significant emissions and sequestering of greenhouse gases. A tax penalizes producers who emit greenhouse gases while a subsidy encourages further expansion of the activity. For example, a carbon tax would expand renewable energy production or allow landowners to collect carbon credits from afforestation as trees sequester carbon dioxide.

MAPGEM is a scalable model and can be expanded in four ways.

- Researchers can add a resource like pesticide by adding the pesticide's price, and the appropriate pesticide usage for each crop and tree.
- Researchers could add a new crop such as coffee. A commodity is more involved because researchers would add coffee to the growing crop tables, the manufacturing processes, and the final domestic demand, export, and import supply.
- Researchers could add new sections such as livestock. Livestock produce manure that producers can utilize for fertilizer and products that Malaysians and foreigners can consume. Of course, the livestock consumes some of the goods and commodities from the agricultural industries.
- Researchers can modify MAPGEM to model another country's agriculture and plantation sectors. For example, Thailand shares a similar climate to Malaysia. Thus, researchers can modify and adapt MAPGEM to model Thai agriculture.

MAPGEM leads to a goldmine of information and potential research papers and grants. MAPGEM includes the production activities at the state level, which is why MAPGEM contains approximately 28 thousand equations. Researchers can explore other avenues of research such as distributional effects of agriculture and government policies on the states or biosecurity issues such as impacts of blight and diseases on particular crops and trees.

2 Economic Models from the Literature

Researchers use a variety of models to study markets and government policies. Every methodology has strengths and weaknesses. We define models into five types in the application of renewable energy and biosecurity. Since economics has a wealth and a large variety of models, some models may fit into two or more categories. This chapter also provides the background literature of economic modeling.

2.1 Econometric Models

Researchers define an equation or system of equations that describe a sector of an economy. Then the researchers collect data and estimate parameters to equation or equations. This method works if researchers have data that covers the pre and post-implementation of the government policy. Unfortunately, renewable energy has little or no data. In addition, researchers cannot estimate equations for cases involving theoretical new technologies because of the lack of data. Several papers in econometrics cover:

- Rivers and Schaufele [2015] study a carbon tax on the agricultural sector in British Columbia, Canada and conclude a carbon tax has little impact on exports.
- Antle et al. [1999] estimate the impact of higher energy prices on the northern plains grain production resulting from the Kyoto Protocol. They estimated production cost would rise between 15 and 27% while net returns drop from 15 to 25%.
- Apergis and Payne [2014] find cointegration between renewable energy consumption, real coal prices, carbon equivalent emissions, and real GDP with a structural break in 2002.
- Kochaphum et al. [2015] show high biodiesel prices expand the oil palm at the expense of coffee, oil palm, rambutan, and rice, and raise prices in Thailand.
- Kuchler and Hamm [2000] find the government's indemnification price determines whether sheep herders turn over infected sheep to the government.

2.2 Simulation Models and Techno-Economic Models

Researchers can easily build simulation models because a variety of software packages allow business people and researchers to develop supply chain models. Although simulation models can estimate supply chains accurately, the models may lack market dynamics such as market demand. In addition, simulation models may not provide dynamic forecasts over time. On the other hand, a techno-economic model is standard in the engineering literature. Researchers build simulated refineries for new technologies and products, but the models assume prices and costs are fixed. The following researchers have utilized simulation and techno-economic models.

- Zhang et al. [2012] build a simulation model of biofuel production in the State of Michigan. Their model includes supply chain activities such as biomass harvesting, processing, transportation, and storage for a biofuel facility and incorporates feedstock delivery cost, energy consumption, and GHG emissions.

- Chase and Henson [2010], Henson [2009] develop the Oil Palm Carbon Budget Simulator (OPCABSIM) and Global Warming Assessment of Palm Oil Production (GWAPP), which simulate a Malaysian palm oil mill. The simulator tracks greenhouse gas emissions and the carbon sequestration of plantation trees. In addition, Roundtable for Sustainable Palm Oil [2017] develop a greenhouse gas calculator for palm oil mills. The software estimates the mill's carbon emissions, so that managers can develop strategies to lower GHG emissions and their carbon footprint. Finally, de Carvalho Lopes et al. [2011] offer an economic feasibility calculator for biodiesel.
- Gapes [2000], Pfromm et al. [2010], Qureshi et al. [2013], Ramey and Yang [2004] study the techno-economic analysis of butanol.
- Elbakidze and McCarl [2005] use stochastic simulation to analyze the outbreak probability, disease spread rate, eradication costs, and damage costs and their impact on the pre and post-outbreak strategies.

2.3 Input-Output Models

The input-output models are based on Leontief production functions that define a matrix for markets and sectors of an economy. The models are easy to solve but suffer from several deficiencies. First, the models treat demand and supply as exogenous and cannot handle changing demand and supply functions. Subsequently, the models lack mechanisms for technological progress, resource substitution, joint production, rising costs, and bottlenecks. The following researchers have developed the following input-output models.

- Australian Farm Institute [2011] study carbon prices on an Australian beef farm. The researchers use three price scenarios, and they predict a carbon price would raise production costs between 1.7% and 4.6% and lower farm net income between 6.2% and 16.5%.
- Horowitz et al. [2017] analyze the economic impact of a carbon tax if the Internal Revenue Service assesses a $49/t CO2-e tax on GHG emissions that grows 2% per year. The analysis assumes the government assesses a carbon tax on tailpipe emissions and not life-cycle emissions, so the government could tax renewable energy under this scenario. The researchers find relative prices could increase between 0 and 24.4% with natural gas, electricity, home heating oil, and petrol exhibiting the largest increases.
- Illukpitiya et al. [2017] estimate the net energy balance of ethanol from warm season grasses. They show ethanol production exhibits a positive energy balance.

2.4 Partial Equilibrium Models

The partial equilibrium models overcome the deficiencies of econometrics, simulation, and input-output models. Partial equilibrium models may represent detailed production chains and require less information, easier to solve, and excel at public policy analysis [Castiblanco et al., 2015]. The straightforward modeling allows researchers to explain the results easily. The models could simulate nonexistent markets or simulate new technologies that industries do not use. Alas, the partial equilibrium models suffer from three deficiencies. First, partial equilibrium models exclude parts of an economy and may lack vital interactions with the missing parts of the economy. Second, the models are sensitive to incorrectly specified elasticities. Finally, models may not allow resources to move across sectors or omits vital linkages between markets and upstream and downstream processing. The examples below show the standard applications of partial equilibrium models.

- Bauer and Kasnakoglu [1990], Siam [2001] construct agricultural models of Turkey and Egypt respectively. The models require little data, but they excel at policy analysis.
- The Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOM-GHG) has a long history. FASOM-GHG is a dynamic, endogenous price model that contains 63 production regions and numerous forestry, crop, and livestock products. Maung and McCarl [2013], McCarl et al. [2000], Ohrel et al. [2010], Szulczyk and McCarl [2010], Szulczyk et al. [2010] use FASOM-GHG to study policies on bioelectricity, biodiesel, ethanol, soil erosion, and climate change. We use FASOM-GHG as the inspiration to develop the MAPGEM model espoused in this book.
- Castiblanco et al. [2015], Korting and Just [2017], Rahdar et al. [2014], Wise et al. [2014] utilize partial equilibrium models to study biodiesel, biomass, and ethanol.
- Cook et al. [2011], Tozer and Marsh [2012] use partial equilibrium models to study biosecurity issues in the apple and beef industries.

2.5 Computable General Equilibrium Models

The computable general equilibrium (CGE) models capture the interactions between the sectors of the economy and overcome this deficiency of the partial equilibrium models. Furthermore, CGE models use simple rules to construct economies mathematically and can capture complex interactions between variables. Nevertheless, CGE models have four drawbacks. First, the heavy aggregation loses production details. Second, the models are also sensitive to the specification of parameters, similar to partial equilibrium models. Third, CGE models could overestimate the impact of biofuels on the agricultural markets as compared to partial equilibrium [Taheripour and Tyner, 2007]. Finally, the CGE models are challenging to build because of data quality problems and information gaps [Feng and Babcock, 2010]. The following are common CGE models in the literature.

- CGE models are popular to study the economic impact of carbon taxes. See, for example, Annicchiarico et al. [2017], Guo et al. [2014], Partnership for Market Readiness [2016], Qi et al. [2016], Wang et al. [2018], Zhang et al. [2017].
- Several researchers use CGE models to capture interactions between land use, deforestation, GHG emissions, and interdependencies between bioelectricity and biofuel production. See, e.g., Calvin et al. [2016], Ignaciuk and Dellink [2006], Suttles et al. [2014], Timilsina [2015], Timilsina et al. [2010], Treesilvattanakul et al. [2014], Winchester and Reilly [2015].
- We could only find one paper applying a CGE model to biosecurity. Productivity Commission [2002] utilizes a CGE to study the outbreak of foot and mouth disease in the Australian cattle industry.

3 Demand and Supply System

The demand and supply functions drive MAPGEM. They determine the prices and quantities for every market and form the backbone of the objective function. Hence, we begin the discussion with them first.

3.1 Demand

MAPGEM contains two sets of demands at the national level. Malaysians consume commodities domestically while foreigners buy Malaysian commodities via exports. Table 3.1 shows the commodities that Malaysia can produce, consume, and export. Table 3.1 includes biodiesel because Malaysia exports it to other countries. Furthermore, one feature of MAPGEM is we treat the waste biomass as commodities. The waste biomass has a zero market price, so the biomass products do not enter into the demand and supply system per se, but the Malaysian industries can utilize the biomass to produce renewable energy, such as ethanol, butanol, and bioelectricity. The Malaysian palm oil mills could also collect the methane from palm oil mill effluents (POME) to flare it and reduce methane's global warming potential.

3.1.1 Constant Elasticity Demand Functions

MAPGEM forecasts demand and supply for commodities between 2020 and 2065 in five-year increments. MAPGEM uses constant elasticity inverse demand functions for each year with a market price in Equation 1. P stands for the market price while C represents domestic consumption. The POP refers to the population forecast for the next 60 years, available from Department of Economic and Social Affairs [2015]. The subscripts denote the commodity (i) and time (t). The demand function includes duties and the goods and services tax (GST). Duty would equal zero for domestic consumption while the government collects duties from exports and imports. Furthermore, the Malaysian government imposes a value-added tax (VAT) known as the Goods and Services Tax (GST). Although the Malaysian repealed the GST in 2018, we leave GST in the model. Finally, MAPGEM computes parameters a_i, b_i, and c_i from the data.

$$P_{i,t}\left(C\right) = a_i C_{i,t}^{b_i} POP_t^{c_i} \left(1 + duty\right)\left(1 + GST\right) \tag{1}$$

3.1.2 Price Elasticity of Demand

MAPGEM calculates the b_i parameter first. This parameter represents the price elasticity of demand. Researchers and analysts usually estimate the price elasticity of demand to determine the consumers' responsiveness to changes in the market price. We show the price elasticity of demand equals b_i. First, we take the partial derivative of 1 and multiply by C_i and divide by P_i. Then substitute 1 for P in 2. All terms drop out except the parameter b_i.

$$\frac{\partial P_i}{\partial C_i} \cdot \frac{C_i}{P_i} = a_i b_i C_i^{b_i - 1} POP_t^{c_i}\left(1 + duty\right)\left(1 + GST\right) \frac{C_i}{a_i C_{i,t}^{b_i} POP_t^{c_i}\left(1 + duty\right)\left(1 + GST\right)} = b_i \tag{2}$$

Table 3.1: Commodities, Wastes, Renewable Energy, and Resources

Source	Products
Cocoa tree	Cocoa bean
Coconut tree	Coconut
Commodities	Banana, durian, kenaf, mango, papaya, pepper, pineapple, rice, and rambutan
Palm oil tree	Palm fatty acid distillates (PFAD), palm kernel cake, palm kernel oil, palm oil, and yellow grease
Rubber tree	Latex
Renewable energy	Bioelectricity, butanol, ethanol, flared methane, palm biodiesel, PFAD biodiesel, and yellow grease biodiesel
Plantation wastes	Empty fruit bunches (EFB), methane, palm fiber, palm fronds, palm oil mill effluent (POME), and palm shell
Waste biomass	Banana residues, coconut husks, pineapple wastes, rice husks, and rice straw
Resources	Land, labor, nitrogen, phosphate, and potash

Table 3.2 shows the demand price elasticities for all commodities in MAPGEM. The negative demand elasticities show the inverse relationship between market price and quantity. Although the table contains elasticities for biomass and byproducts, such as rice straw, empty fruit baskets (EFB), and palm oil mill effluent (POME), the market prices equal zero. Thus, the biomass and byproducts do not enter the demand functions, and the elasticities do not influence the market prices and quantities of other commodities. For unknown elasticities, we set the elasticities to 0.75. Demands have negative elasticities while import and population have positive elasticities. Equation 3 relates the price elasticity of demand to parameter b because MAPGEM uses inverse demand functions. MAPGEM has one caveat; a demand elasticity cannot equal one because it would cause a division by zero in the objective function.

$$\epsilon_{D_i} = \frac{\partial C_i}{\partial P_i}\frac{P_i}{C_i} = \frac{1}{b_i} \tag{3}$$

3.1.3 Population Elasticity

Table 3.2 includes population elasticities. A growing population consumes more products and commodities and raises food prices. The inverse demand function in Equation 1 captures future demand for Malaysian products. Similar to price elasticity, we show the population elasticity equals parameter c_i. Accordingly, we take the partial derivative of 1 respect to population. Then multiply by population and divide by price. The population elasticity for the inverse demand function equals parameter c_i.

$$\frac{\partial P_i}{\partial POP_t} \cdot \frac{POP_t}{P_i} = a_i c_i C_i^{b_i} POP_t^{c_i - 1} \left(1 + duty\right) \left(1 + GST\right) \frac{POP_i}{a_i C_{i,t}^{b_i} mathitPOP_t^{c_i} \left(1 + duty\right) \left(1 + GST\right)} = c_i \tag{4}$$

Researchers and analysts estimate the population elasticity for demand functions. Equation 4 defines the population elasticity for commodity i. However, MAPGEM utilizes the inverse demand functions, so we manipulate the equations to find the relationship between Equations 4 and 5.

Table 3.2: Price Elasticity of Domestic Demand, Exports, Imports, and Population

Commodity	Price Elasticity of Domestic Demand	Price Elasticity of Exports	Price Elasticity of Imports	Population Elasticity
Banana	-1.0607	-1.0607		
Banana residues	**-0.75**	**-0.75**	**0.75**	**0.75**
Cocoa				
Coconut	-1.0607	-1.0607		
Coconut husks	**-0.75**	**-0.75**	**0.75**	**0.75**
Durian	-1.0607	-1.0607		
Empty fruit baskets (EFB)	**-0.75**	**-0.75**	**0.75**	**0.75**
Kenaf				
Latex				
Mango	-1.0607	-1.0607		
Methane	**-0.75**	**-0.75**	**0.75**	**0.75**
Palm biodiesel				
Palm fiber	**-0.75**	**-0.75**	**0.75**	**0.75**
Palm fronds	**-0.75**	**-0.75**	**0.75**	**0.75**
Palm kernel cake				
Palm kernel oil	-1.2500	-1.2500		
Palm oil	-1.2500	-1.2500		0.2493
Palm shell	**-0.75**	**-0.75**	**0.75**	**0.75**
Papaya	-1.0607	-1.0607		
Pepper				
PFAD				
Pineapple	-1.0607	-1.0607		
Pineapple wastes	**-0.75**	**-0.75**	**0.75**	**0.75**
POME	**-0.75**	**-0.75**	**0.75**	**0.75**
Rambutan	-1.40000	-1.0607		
Rice	-0.15400	-1.8590		
Rice husks	**-0.75**	**-0.75**	**0.75**	**0.75**
Rice straw	**-0.75**	**-0.75**	**0.75**	**0.75**
Yellow grease	-0.75	-0.75	0.75	0.75

Sources: Palm oil elasticities are from Yusoff [1998]. Fruits and oils elasticities from Sheng et al. [2008]. Rambutan and rice from Kochaphum et al. [2015]. Table is replicated in MAPGEM called elasticities(commodities, elasticity).

$$\epsilon_{POP} = \frac{\partial C_i}{\partial POP} \frac{POP}{C_i} \tag{5}$$

We manipulate algebraically to calculate the population elasticity for an inverse demand function. Equation 6 shows the parameter c_i equals the population elasticity divided by the price elasticity of demand. We do not show in the equation below, but we add a binary variable called sensitivity that switches all population elasticities to 1.25 for a sensitivity analysis.

$$\frac{\epsilon_{POP}}{\epsilon_{D_i}} = \left(\frac{\partial C_i}{\partial POP} \frac{POP}{C_i}\right) \left(\frac{\partial P_i}{\partial C_i} \frac{C_i}{P_i}\right) = \frac{\partial P_i}{\partial POP} \frac{POP}{P_i} = c_i \tag{6}$$

We show how to calculate Parameter a_i by setting the population, POP, to the base year 2015. Accordingly, we solve Equation 1 to yield 7.

$$a_i = \frac{P_{i,t}}{C_{i,t}^{b_i} POP_t^{c_i} (1 + duty)(1 + GST)} \tag{7}$$

Table 3.3 shows the domestic, export, and import prices. Malaysian agricultural prices fluctuate widely and some years had missing data, so we averaged prices between 2011 and 2015. It is a programming convenience to have separate prices for domestic consumption, exports, and imports, even though the model will equate equal prices across domestic consumption, exports, and imports. Otherwise, the price difference between markets for the same goods would result in arbitrage. Many commodities have different grades and products. Consequently, we calculated prices by dividing the total value of production by production quantity. If production value was not available, then we utilize export value and quantity exported. Furthermore, the agricultural wastes and residues have a zero price for domestic consumption and exports since no market exists. However, the import price cannot equal zero. Otherwise, MAPGEM could import an infinite amount of waste biomass to make renewable energy such as bioelectricity, bioethanol, and biobutanol. Consequently, the import prices are set 100,000 RM per ton. Finally, import prices must always exceed or equal export prices. If the import prices lie below export prices, producers can import commodities that they immediately export for an arbitrage profit.

Table 3.4 shows the 2015 domestic, export, import, production, and stored quantities in Malaysia. The Malaysian government does not report domestic consumption for many commodities, and the food industry may use them to produce consumer products. Therefore, we treat domestic consumption as a residual demand. From Equation 8, domestic consumption is left over after adding production plus imports minus exports. Similar to prices, export and import quantities can vary. Consequently, we average import and export quantities between 2011 and 2015. When MAPGEM calculates parameters a and c, it divides by quantity. Thus, quantities cannot equal zero because a zero in the denominator would result in a division by zero. Furthermore, MAPGEM does not utilize the production numbers. Instead, MAPGEM creates a calibration table to compare 2015 quantities and the model's predicted quantities. One may find the calibration table in the last table of the National Output. Finally, storage stays fairly constant over time. Currently, MAPGEM does not place commodities into storage because of the additional code and solving time required.

$$domestic\ demand_{2015} = production_{2015} + imports_{2015} - exports_{2015} \tag{8}$$

Table 3.3: Average Prices between 2011 and 2015 (RM per Metric Ton)

Commodity	Domestic	Exports	Imports
Banana	1,788.05	1,788.05	1,788.05
Banana residue			100,000.00
Cocoa bean	9,878.35	9,878.35	9,878.35
Coconut	1,250.00	1,250.00	1,250.00
Coconut husk			100,000.00
Durian	6,091.67	6,091.67	100,000.00
EFB			100,000.00
Kenaf	2,000.00	2,000.00	100,000.00
Latex	6,107.28	6,107.28	6,107.28
Mango	3,552.29	3,552.29	3,552.29
Methane			100,000.00
Palm biodiesel	3,102.22	3,102.22	100,000.00
Palm fiber			100,000.00
Palm frond			100,000.00
Palm kernel cake	431.61	431.61	431.61
Palm kernel oil	3,892.03	3,892.03	3,892.03
Palm oil	2,630.09	2,630.09	2,630.09
Palm shell			100,000.00
Papaya	1,613.58	1,613.58	1,613.58
Pepper	20,479.41	20,479.41	100,000.00
PFAD	2,228.43	2,228.43	2,228.43
Pineapple	1,643.29	1,643.29	1,643.29
Pineapple waste			100,000.00
POME			100,000.00
Rambutan	2,742.21	2,742.21	100,000.00
Rice	1,164.25	1,164.25	1,164.25
Rice husk			100,000.00
Rice straw			100,000.00
Yellow grease			100,000.00

Sources: Prices for bananas, durian, mango, papaya, pineapple, and rambutan come from Jabatan Pertanian Malaysia [2011, 2012, 2013, 2014, 2015]. Cocoa from Ministry of Plantation Industries and Commodities [2015a]. Latex is farmgate price and comes from Department of Statistics Malaysia [2016a]. Table replicated in MAPGEM called price_cost(commodities, activities).

Table 3.4: 2015 Commodity Quantities (metric tons)

Commodity	Domestic	Exports	Imports	Production
Banana	304,182.4	20,004.3	8,686.7	315,500.0
Banana residue	631,000.0	0.1	0.1	631,000.0
Cocoa bean	271,416.1	56,183.6	325,899.7	1,700.0
Coconut	610,117.3	42,404.7	57,425.0	595,097.0
Coconut husk	202,333.0	0.1	0.1	202,333.0
Durian	368,271.0	0.1	0.1	368,271.0
EFB	21,635,702.0	0.1	0.1	21,635,702.0
Kenaf	11,600.0	0.1	0.1	11,600.0
Latex	715,459.4	854,835.3	848,194.7	722,100.0
Mango	19,297.3	6,797.7	3,423.0	22,672.0
Methane	607,766.5	0.1	0.1	607,766.5
Palm biodiesel	310,624.2	170,624.5	0.1	481,248.8
Palm fiber	13,276,453.5	0.1	0.1	13,276,453.5
Palm frond	56,252,825.2	0.1	0.1	56,252,825.2
Palm kernel cake	919,122.6	2,512,303.4	9,051.3	3,422,374.7
Palm kernel oil	1,607,708.9	1,122,995.8	252,433.4	2,478,271.3
Palm oil	2,419,596.8	17,692,487.6	953,332.0	19,158,752.4
Palm shell	5,408,925.5	0.1	0.1	5,408,925.5
Papaya	38,001.6	22,650.7	27.3	60,625.0
Pepper	15,510.8	12,789.3	0.1	28,300.0
PFAD	421,543.9	561,897.2	0.1	983,441.0
Pineapple	256,492.7	18,125.3	2,048.0	272,570.0
Pineapple waste	190,799.0	0.1	0.1	190,799.0
POME	49,172,050.0	0.1	0.1	49,172,050.0
Rambutan	65,649.0	0.1	0.1	65,649.0
Rice	3,820,309.3	4,115.7	975,425.0	2,849,000.0
Rice husk	626,780.0	0.1	0.1	626,780.0
Rice straw	1,139,600.0	0.1	0.1	1,139,600.0
Yellow grease	50,000.0	0.1	0.1	50,000.0

Sources: Exports and imports for banana, cocoa, coconut, mango, papaya, pineapple, rice, and rubber originate from Food and Agriculture Organization of the United Nations [2013]. Biodiesel production and exports from Wahab [2016]. Yellow grease from Kheang et al. [2006]. Production comes from Department of Statistics [2016]. The agricultural and animal wastes and residues are derived from the production coefficients. Table is replicated in commodity_quantities(commodities, activities) in MAPGEM.

Table 3.5 shows the population forecasts for the world and Malaysia. The world population indicates the demand for Malaysian exports while the Malaysian population estimates the consumption of domestically produced goods. Department of Economic and Social Affairs [2015] provides the population forecasts for 2015, 2030, 2050, and 2100. We interpolate missing numbers using trend regression, $Population_t = \beta_1 + \beta_2 t$. We also utilize the Malaysian population forecasts to estimate the electricity, petrol, and diesel consumption for the next 55 years.

Table 3.5: Population Forecast 2015 - 2075

Year	World	Malaysia
2015	7,349,472,000	30,331,000
2020	7,941,626,030	33,709,276
2025	8,129,626,574	34,215,081
2030	8,322,077,617	34,728,476
2035	8,519,084,516	35,249,574
2040	8,720,755,120	35,778,491
2045	8,927,199,833	36,315,345
2050	9,138,531,671	36,860,254
2055	9,354,866,325	37,413,340
2060	9,576,322,227	37,974,724
2065	9,803,020,611	38,544,532
2070	10,035,085,581	39,122,890
2075	10,272,644,179	39,709,926

Source: Department of Economic and Social Affairs [2015]. Table replicated in MAPGEM called forecast(year, prediction).

3.2 Import Supply

MAPGEM contains two supply functions: Resources and imports. To produce commodities, Malaysian industries use land, labor, and fertilizer. We place resources in the next section because it differs in equations and code. Nevertheless, imports share similarities with domestic and export demand functions and are aggregated at the national level. Equation 9 shows the inverse supply function for imports. The inverse supply function lacks a population term and has only two parameters a_i and b_i. The price mechanism is still present in the import function. A greater demand for imports induces rising import prices. As the Malaysian population increases and buys more imports, the larger quantity leads to greater supply. In this case, the price elasticity of supply is positive, and the parameter b_i is positive.

$$P_{i,t}\left(I\right) = a_i I_{i,t}^{b_i} \left(1 + duty\right)\left(1 + GST\right) \tag{9}$$

Since MAPGEM utilizes the inverse demand function, parameter b_i equals the inverse of the price elasticity of supply, which Equation 10 shows. Table 3.2 also includes the price elasticity of imports.

$$\epsilon_{S_i} = \frac{\partial I_i}{\partial P_i}\frac{P_i}{I_i} = \frac{1}{b_i} \tag{10}$$

We calculate the parameter a_i in the same manner as in the inverse demand functions. The import (I) supply lacks a parameter c_i in Equation 11 because a rising population does not directly influence imports. Since import supply shares similar equations and code with the demand functions, Table 3.3 includes import prices while Table 3.4 holds import quantities.

$$a_i = \frac{P_{i,t}}{I_{i,t}^{b_i}\left(1 + duty\right)\left(1 + GST\right)} \tag{11}$$

3.3 Resource Supply

The Malaysian industries grow, harvest, and produce crops at the state level. Malaysia has a tropical climate, and rainfall, soil composition, and altitude differ between regions that lead to different crop yields. We model regional differences in four ways. First, each state can have a different crop and plantation yields. Second, producers in each state use different amounts of fertilizer per crop (or plantation) because soil fertility and composition differ. Third, each state has different labor productivities. However, we could not find enough detail at the state level to allow labor productivity to differ except coconut and rice. Finally, each state varies in cultivating, growing, and harvesting costs. Unfortunately, we could not find enough data to exploit local growing and harvesting costs.

Equation 12 shows the inverse supply function for resource r and appears in the objective function. MAPGEM allows resources for labor, nitrogen, phosphorous, and potash. Price denotes the price or cost of the resource while RU stands for resources used. MAPGEM calculates parameters e_r and d_r from data. In theory, we could allow states to differ in parameters e_r and d_r, but lack of data prevents this level of detail.

$$P_{r,t}\left(RU\right) = e_r RU_{r,t}^{d_r} \tag{12}$$

Equation 13 shows d relates inversely to the price elasticity of supply.

$$\epsilon_{S_r} = \frac{\partial RU_r}{\partial P_r}\frac{P_r}{RU_r} = \frac{1}{d_r} \tag{13}$$

Equation 14 shows the calculation of the parameter e_r. MAPGEM includes four resources: labor, nitrogen, phosphorous, and potash. Table 3.6 shows the supply elasticities and price. Elasticities are positive because suppliers provide more resources for a greater market price. Moreover, MAPGEM allows different salary and fertilizer prices by state, but, again, the researchers could not find enough information to exploit regional difference. The price of labor in 2015 equals roughly 20,809.36 RM per worker per year. We used trend regression to estimate 2015 rural, bottom 40% of income from Prices Income and Expenditure Statistics Division [2014]. Furthermore, Malaysia imports most of its fertilizers [Sabri, 2009]. Although fertilizer comes in different mixtures, on average, the price of fertilizer equals 1,070.40 RM per ton for 2009. We derive this number by dividing fertilizer import value by import quantity for all fertilizer types. Then the producers' price index deflates all prices and costs to 2015 prices, the first year of the model.

$$e_r = \frac{P_{r,t}}{RU_{r,t}^{d_r}} \tag{14}$$

Table 3.6: Resource Supply Elasticity and Cost

Resource	Year	Price Elasticity of Supply	Price or Costs	Producers Price Index	2014 Price
Labor	2015	1.30	20,809.36	1.0000	20,809.36
Nitrogen	2009	1.00	1,070.40	0.9080	1,178.85
Phosphorus	2009	1.00	1,070.40	0.9080	1,178.85
Potash	2009	1.00	1,070.40	0.9080	1,178.85

Source: Fertilizer price comes from the average prices from Sabri [2009]. Missing values for labor annual wages is extrapolated using logarithm trend regression of data from Department of Statistics Malaysia [2014b]. Producer price index from Department of Statistics Malaysia [2014a]. The elasticities from the table are entered into table, prod_elasticity(resources) while resource_cost(resources) contain the resource prices.

GAMS requires only one equation to relate resource usage (RU) to growing crops and trees. Equation 15 comprises of three decision variables: Cropland (CL), hectares (H), and resources used (RU). The decision variables have three indices: time (t), state, (s), and a group identifier. Agriculture is split into crops (c) and plantations (p) while r indicates the particular resource. The matrices, crop resources (CR) and plantation resources (PR) contain labor and fertilizer information for each crop and plantation tree for each state.

$$\sum_{c} CL_{t,s,c} \cdot CR_{s,c,r} + \sum_{p} H_{t,s,p} \cdot PR_{s,r,p} \leq RU_{t,s,r} \tag{15}$$

Food and Agriculture Organization of the United Nations [2004] provides fertilizer usage for all Malaysian crops and trees at the state level except kenaf. Appendix A shows all tables for fertilizer since they are quite numerous. The average fertilizer usage substitutes for missing values in a state.

We could only find details of labor per state for coconuts and rice. For the other crops and plantations, we utilize two methods to approximate labor intensity. For the first method, worker productivity equals total labor employed for each crop divided by total crop hectares, which Table 3.7 shows. The Malaysian government only provides employment data for estates for rubber and palm plantations. The labor/hectare productivity is calculated by dividing total hectares for the estate by total laborers employed in the industry. We apply the same labor/hectare productivity to small plantations because the numbers are not available.

Table 3.8 shows the second method. The number of employed labor equals total labor cost per hectare divided by annual worker income. We assume a person works full time on the farm or plantation and earn wages annually. Monthly income comes from the bottom 40 percentile of rural workers. We used logarithm trend regression, $\ln(wages_t) = \beta_1 + \beta_2 t$, to interpolate missing values.

3.4 GAMS Code

The code to calculate parameter b_i for domestic consumption and exports is shown below.

```
b(commodities, 'domestic') = 1 / elasticities(commodities, 'e_domestic') ;
b(commodities, 'exports') = 1 / elasticities(commodities, 'e_exports') ;
```

Table 3.7: Labor Employed

Commodity	Year	Hectares	Workers	Labor/Hectare
Cocoa	2004			0.1771
Coconut				
Johor	2015	11,550.00	8,817	0.7634
Kedah	2015	1,931.00	1,474	0.7633
Kelantan	2015	8,078.00	6,166	0.7633
Melaka	2015	2,451.00	1,871	0.7634
N. Sembilan	2015	1,576.00	1,203	0.7633
Pahang	2015	3,988.00	3,044	0.7633
Penang	2015	51.00	39	0.7647
Perak	2015	9,446.00	7,211	0.7634
Perlis	2015	370	282	0.7622
Selangor	2015	9,721.00	7,421	0.7634
Terengganu	2015	1,964.00	1,499	0.7632
Sabah	2015	16,481.00	12,581	0.7634
Sarawak	2015	14,222.00	10,857	0.7634
Palm Oil	2014	4,585,227	451,507	0.0985
Rice				
Johor	2015	1,286.47	1,016	0.7898
Kedah	2015	89,946.46	58,476	0.6501
Kelantan	2015	33,319.88	24,789	0.7440
Melaka	2015	1127.454255	1,769	1.5690
N. Sembilan	2015	895.1086098	1,068	1.1932
Pahang	2015	7,864.68	4,675	0.5944
Penang	2015	10,207.27	6,623	0.6489
Perak	2015	33,448.21	22,321	0.6673
Perlis	2015	22,325.11	13,518	0.6055
Selangor	2015	15,161.05	9,855	0.6500
Terengganu	2015	6,830.48	6,635	0.9714
Sabah	2015	15,535.67	10,530	0.6778
Sarawak	2015	52,989.15	35,915	0.6778
Rubber	2015	76,751	11,640	0.1517

Sources: Cocoa information came from Azhar and Lee [2004]. Coconut and rice from Department of Agriculture [2015]. Palm plantations came from Jabatan Perangkaan Malaysia [2015]. Rubber plantations came from Department of Statistics Malaysia [2016a]. The labor productivity is inputted into crop_resources(state, crops, resources) for crops in MAPGEM and plantation_resources(state, type, resources) for plantation trees.

Table 3.8: Labor Cost and Annual Income.

Commodity	Year	Labor Cost (RM/hectares)	Annual Income (RM)	Labor / Hectare
Banana	2010	4,946.67	14,495.63	0.3413
Cocoa	2004	1,400.00	9,396.00	0.1490
Coconut	2015	1,936.00	20,809.36	0.0930
Durian	2010	2,087.25	14,495.63	0.1440
Kenaf	2016	567.93	22,369.85	0.0254
Mango	2010	11,947.87	14,495.63	0.8242
Pepper	2005	10,644.50	10,097.54	1.0542
Pineapple	2010	4,990.00	14,495.63	0.3442
Rambutan	2010	2,076.75	14,495.63	0.1433
Rubber	2009	1,143.08	12,396.00	0.0922

Sources: Banana derived from Anem [2010a]. Cocoa from Azhar and Lee [2004]. Coconuts from Michael [2015]. Durian from Anem [2010b]. Kenaf from Abdelrhman et al. [2016]. Mango from Anem [2010c]. Pepper derived from George et al. [2005]. Pineapple from Anem [2010d]. Rambutan from Anem [2010e]. Rubber from Malaysian Rubber Board [2009]. Finally, wages from Department of Statistics Malaysia [2014b]. The table information is entered into MAPGEM in crop_resources(state, crops, resources) for crops and plantation_resources(state, type, resources) for plantation trees.

The code calculates Parameters c_i and a_i for both domestic and export demands. We must calculate Parameter c_i before a_i. The Parameter c_i multiplies by -1 to ensure a rising population leads to higher commodity market prices. The elasticity contains a binary variable, sensitivity, that switches all population elasticities to 1.25 for the sensitivity analysis.

```
c(commodities, 'domestic') = (-1)*( elasticities(commodities, 'population')
* ( 1 - sensitivity ) + sensitivity * 1.25 )
/ elasticities(commodities, 'e_domestic');

c(commodities, 'exports') = (-1)*( elasticities(commodities, 'population')
* ( 1 - sensitivity ) + sensitivity * 1.25 )
/ elasticities(commodities, 'e_exports');

a(commodities, 'domestic') = price_cost(commodities, 'domestic')
/ ( ( 1 + GST('domestic')) * ( 1 + duties('domestic')) *
commodity_quantities(commodities, 'domestic')**b(commodities, 'domestic')
* forecast('y2015', 'malaysia_pop')** c(commodities, 'domestic') ) ;
```

The Parameters a_i and b_i are calculated similarly for the import supply function. The supply function excludes Parameter c_i.

```
b(commodities, 'imports') = 1 / elasticities(commodities, 'e_imports') ;

a(commodities, 'imports') = price_cost(commodities, 'imports')
/ ( ( 1 + GST('imports')) * ( 1 + duties('imports')) *
commodity_quantities(commodities, 'imports')** b(commodities, 'imports') ) ;
```

The following lines of GAMS code calculates Parameters d_r and e_r for the resource inverse supply functions. Parameter e_r must be calculated first before d_r.

```
e(state, resources) =  1 / prod_elasticity(resources) ;

d(state, resources) =  resource_cost(resources) / ( total_resources_2015(state,
```

```
resources)**e(state, resources) );
```

GAMS require only one equation to relate growing crops and plantations to resource usage. The decision variables are cropland, hectares, and resources used. Cropland represents the crops grown in hectares for each year and state while hectares holds the plantation trees in hectares. The matrices are defined as crop resources and plantation resources respectively. Finally, the decision variable resources used holds total resources utilized for each year and state.

```
employ_resources(year, state, resources)..

sum(crops, cropland(year, state, crops) * crop_resources(state, crops,
resources) ) + sum(type, hectares(year, state, type) *
plantation_resources(state, type, resources) ) =l=
resources_used(year, state, resources);
```

4 Social Welfare

The social welfare function drives MAPGEM and serves as the objective function that maximizes consumers' plus producers' surplus over 55 years in five-year intervals. The objective function includes revenue from renewable energy, carbon taxes/subsidies, and the costs from cultivating, growing, harvesting and processing costs for crops and plantations.

4.1 Producers' and Consumers' Surpluses

The discount rate connects the time periods together, and all benefits and costs are discounted to 2015. Since MAPGEM covers a long-time span, small differences in the discount rate can cause results to diverge over time. For example, the Rule 72 defines how long a variable doubles given a constant growth rate. A growth rate of 2% per year means a variable can double in 36 years. Since MAPGEM forecasts 55 years into the future, a small growth rate can double production values. Developed countries discount rates range between 3 and 7% while Asian spans from 9 to 13% for long rotation forestry rates. Asian countries also have greater replanting rates. The user can define the discount rate in GAMS. Equation 16 shows the discount rate when time starts at 2015 (t=1) and ends 2070 (t=12).

$$discount = \left(1 + \frac{discount\ rate}{100}\right)^{-(5t-5)} \tag{16}$$

Equation 17 shows the consumers' surplus equals the integral of the demand function from Equation 1 for one commodity (i) at one point in time (t). The * indicates the optimal price to maximize the consumers' surplus for domestic consumption (C). We assume the agricultural markets are competitive. Furthermore, we assume Malaysia is a large producer whereas expanding oil palm plantations lead to lower market prices for palm oil products if other factors do not change. The consumers' surplus for exports is similar except E replaces C in the equation. The commodity (i) and domestic consumption and exports also differ in Parameters a_i, b_i, c_i, GST, and duty. The population (POP) of Malaysia shifts the domestic demand function while the world population shifts export demand. Malaysians and foreigners demand commodity i.

$$CS_{C_{i,t}} = \int_0^{C^*_{i,t}} P_{i,t}\left(C_{i,t}\right) dC_{i,t} = \frac{a_i \cdot C_{i,t}^{b_i+1} POP_t^{c_i}\left(1 + duty\right)\left(1 + GST\right)}{1 + b_i} \tag{17}$$

Malaysians can import commodity i at the time (t). Equation 18 shows producers' surplus for imports (I), which is the integral of the import inverse supply function. The import supply shares similar parameters as the demand functions for a_i, b_i, duty, and GST, but they differ in magnitudes, which is why they have a subscript i.

$$PS_{I_{i,t}} = \int_0^{I^*_{i,t}} P_{i,t}\left(I_{i,t}\right) dI_{i,t} = \frac{a_i \cdot I_{i,t}^{b_i+1}\left(1 + duty\right)\left(1 + GST\right)}{1 + b_i} \tag{18}$$

Finally, Equation 19 shows the producers' surplus for the resources used (RU) to cultivate crops and plantations. Producers use r resources in each state (s) for each time (t) period. The producers' surplus has Parameters d_r and e_r that depend on resource type and state.

$$PS_{RU_{r,t}} = \int_0^{RU^*_{r,s,t}} P_{r,s,t}\left(RU_{r,s,t}\right) dRU_{r,s,t} = \frac{e_r \cdot RU_{r,s,t}^{d_r+1}}{1+d_r} \tag{19}$$

Equation 20 puts the endogenous prices together for consumers' plus producers' surpluses with four decision variables: domestic consumption (C), exports (E), imports (I), and resources used (RU). All decision variables except resources have commodities (i) at the time (t). Resources used has resources (r) at the time (t) for each state (s). Table 4.1 itemizes all the variables incorporated into MAPGEM. Matrices holds values for parameters a_i, b_i, and c_i because they differ for domestic consumption, exports, and imports for commodities i. A separate matrix holds the values for parameters d_r and e_r for resources (r). Other terms include revenue from renewable energy, carbon taxes/subsidies, and cultivating, harvesting, processing, and transportation costs.

$$\begin{aligned} max\ B = &\left(1+\frac{\delta}{100}\right)^{-(5t-5)} \\ &\sum_t \left[\sum_i \left[\int_0^{C^*} P_{i,t}^C\left(C_{i,t}\right) dC_{i,t} + \int_0^{E^*} P_{i,t}^E\left(E_{i,t}\right) dE_{i,t} - \int_0^{I^*} P_{i,t}^I\left(I_{i,t}\right) dI_{i,t}\right]\right. \\ &\left.+other\ terms - \sum_s \sum_r \int_0^{RU^*} P_{r,s,t}^{RU}\left(RU_{r,s,t}\right) dRU_{r,s,t}\right] + TC \end{aligned} \tag{20}$$

Terminal conditions (TC) places a value on cleared land for newly planted oil palms in the last time period. Newly planted oil palms yield zero harvests. Equation 21 shows the terminal condition. Oil palm plantations receive 5,000 RM to develop one hectare (H) of land with newly planted oil palm trees in the state (s). Technically, the model ends in y2065, but MAPGEM estimates to y2070 that helps overcome the terminal condition. We could extend MAPGEM to y2075 to overcome this problem, but the problem appears minor.

$$+\left(1+\frac{discount\ rate}{100}\right)^{-(5t-5)} \cdot 5000 \cdot \sum_s H_{y2070,s,oil\ palm\ 0y} \tag{21}$$

The GAMS code replicates the mathematical notation. The code below shows the discounted welfare function. We decompose social welfare by time because researchers may want the total social welfare over time. The second part of the code contains the terminal condition for newly planted oil palms.

```
max_welfare..

total_benefit =e= sum(year, (1 + discount / 100)**(-(5*ord(year) - 5)) * welfare(year) )
+ (1 + discount / 100)**(-(5*card(year) - 5)) * land_value
* sum(state, hectares('y2070', state, 'oil_palm_0y') ) ;
```

The GAMS code shows the code for the consumers' surplus of domestic consumption. The only caveat is the domestic quantity has a one added. A non-linear demand function cannot have a quantity of zero because the demand function never intersects the price axis. Thus, adding a one allows the quantity to be equal zero. Planting new oil palm trees requires 10 years for trees to become mature.

```
social_welfare..

welfare(year) =e= sum(commodities, a(commodities, 'domestic')
```

Table 4.1: MAPGEM Sets and Variables

Sets	Items
commodities (i)	banana, banana residue, cocoa bean, coconut, coconut husk, durian, efb, kenaf, latex, mango, methane, palm biodiesel, palm fiber, palm frond, palm kernel cake, palm kernel oil, palm oil, palm shell, papaya, pepper, pfad, pineapple, pineapple waste, pome, rambutan, rice, rice husk, rice straw, and yellow grease
crops (c)	banana tree, durian tree, kenaf stalk, mango tree, papaya tree, grow pepper, pineapple plant, paddy, and rambutan tree
fossil energy (fe)	petrol, diesel, and electricity
GHG gases (gg)	CO2, CH4, and N2O
plantation (p) trees	cocoa trees, coconut trees, forest, oil palm 0y, oil palm 5y, oil palm 10y and rubber trees
processing plantations (pp)	
processing crops (pc)	
processing energy (pe)	
renewable energy (re)	biodiesel, bioelectricity, butanol, ethanol, and flare methane
resources used (ru)	labor, nitrogen, phosphorus, and potash
state (s)	Johor, Kedah, Kelantan, Melaka, Negeri Sembilan, Pahang, Penang, Perak, Perlis, Selangor, Terengganu, Sabah, and Sarawak
time (t)	y2015, y2020, y2025, y2030, y2035, y2040, y2045, y2050, y2055, y2060, y2065, 2070
Subsets	
crop products (cp)	banana, banana residue, durian, kenaf, mango, papaya, pepper, pineapple, pineapple waste, rambutan, rice, rice husk, and rice straw
plantation products (ppp)	cocoa bean, coconut, coconut husk, efb, latex, methane, palm biodiesel, palm fiber, palm frond, palm kernel cake, palm kernel oil, palm oil, palm_shell, pfad, pome, and yellow grease
Subsets	
Decision variable	bioenergy (B), consumption (C), convert (CN), crop inputs (CI), cropland (CL), energy inputs (EI), exports (E), hectares (H), plantation inputs (PI), production (P), resources used (RU), imports (I), and transfer (T)

```
* (consumption(year, commodities) + 1)**(b(commodities, 'domestic') + 1 )
* forecast(year, 'malaysia_pop')**c(commodities, 'domestic')
* ( 1 + GST('domestic')) * ( 1 + duties('domestic'))
/ ( b(commodities, 'domestic') + 1 )
```

The following GAMS code is for exports and is identical to domestic consumption.

```
+ a(commodities, 'exports') * (exports(year, commodities) + 1)
**(b(commodities, 'exports') + 1 ) * forecast(year, 'world_pop')
**c(commodities, 'exports') * ( 1 + GST('exports'))
* ( 1 + duties('exports')) / ( b(commodities, 'exports') + 1 )
```

The GAMS code below shows the producers' surplus from imports. A one is added to import quantity because the supply function does not intersect the price axis. The one allows the import quantity to be equal zero. The negative sign indicates money leaves Malaysia to pay for imports.

```
- a(commodities, 'imports') * (imports(year, commodities) + 1)
**(b(commodities, 'imports') + 1 ) * ( 1 + GST('imports'))
* ( 1 + duties('imports')) / ( b(commodities, 'imports') + 1 )  )
```

The last snippet of GAMS code handles the producers' surplus from the resource used. Since production occurs at the state level, the resource cost must sum over the state and resource type. Similarly, a one is added to the quantity of a resource since a nonlinear supply function never intersects the price axis.

```
- sum((state, resources), d(state, resources)
*(resources_used(year, state, resources) + 1)**(e(state, resources) + 1 )
/ (e(state, resources) + 1 ) )
```

4.2 Other Revenues and Costs

The objective function includes revenues, subsidies, and costs for production, harvesting, and growing. For example, the palm oil mills can sell renewable energy (re) to the fossil fuel markets for a fixed exogenous price, P. Equation 22 shows the integral, which equals total revenue, quantity times price. Similarly, if all growing, harvesting, and production costs are constant and equal marginal costs, then the quantity times marginal costs equal the variable costs. The integrals exclude the constant of integration since the constant does not affect optimization.

$$CS = \int_0^{Q^*_{re,t}} P_{re} dQ_{re,t} = P_{re} \cdot Q_{re,t} \tag{22}$$

Equation 23 shows agricultural producers receive price (P) for selling renewable energy (re) to the transportation or electricity market. Ag producers supply quantity of bioenergy (B) at the time (t), in the state (s), and renewable energy type (re). Agricultural producers can also receive a subsidy from the government. The total energy supplied is summed over the states (s) and renewable energy(re). The equation contains two indicator functions. Users can turn on or off whether producers can sell a particular renewable energy. The ϕ is an indicator function and serves as an on-off switch. Also, the second indicator function implements the price for 2020 and after.

$$+\sum_{s}\sum_{re} \phi_{re}\left(turn\ on\right) \cdot \phi_{re}\left(t > 1\right) \cdot \left(P_{re} + subsidy_{re}\right) \cdot B_{t,s,re} \tag{23}$$

Producers incur a production cost as they sell a quantity of renewable energy. MAPGEM allows two places for bioenergy production costs. First, producers can either pay for the cost via the Leontief production functions or directly associated with the amount of bioenergy sold in Equation 24. The cost is aggregated over the states (s) and renewable energy (re) type. This equation has no indicator functions, and MAPGEM always imposes the renewable energy costs for all years. The vector, energy costs (EC), holds the marginal costs to produce renewable energy. At last, MAPGEM allows the bioenergy costs to decrease over time. The cost reduction (CR) is in percent.

$$-\sum_{s}\sum_{re} EC_{re} \cdot B_{t,s,re} \cdot \left(1 - \frac{CR}{100}\right)^{(5t-5)} \tag{24}$$

The following shows the GAMS code. The $ indicates a conditional statement for the year when t = 1 for 2015.

```
+ sum((state, renewable_energy), turn_on_energy(renewable_energy)
* ( energy_prices(renewable_energy) + energy_subsidy(renewable_energy) )
* bioenergy(year, state, renewable_energy) )$(ord(year) > 1 )

- sum((state, renewable_energy), energy_costs(renewable_energy)
* bioenergy(year, state, renewable_energy)
* (1 - cost_reduction(renewable_energy) / 100)
**( 5 * ord(year) - 5) )
```

Equation 25 imposes a carbon tax on greenhouse gas (GHG) emissions. (A sink would be negative and transforms a tax into a subsidy). The matrix, greenhouse gases (GHG) sums the total greenhouse gases released into the atmosphere for time (t), state (s), and greenhouse gas type (ghg). The matrix, global warming potential (GWP), converts all gases to their equivalent carbon dioxide. The user can specify the carbon tax. The $\frac{12}{44}$ converts the carbon tax to a carbon dioxide tax since carbon has a mass of 12 and carbon dioxide equals 44. The equation also contains an indicator function, $\phi()$, and only turns on for the year 2020 and later.

$$-\,carbon\ tax \cdot \frac{12}{44} \sum_{s}\sum_{ghg} \phi_{re}\,(t > 1) \cdot GHG_{t,s,ghg} \cdot GWP_{ghg} \tag{25}$$

The GAMS code for a carbon tax applied to all emissions is shown below with the $ imposing the condition of the year 2020 and later:

```
- carbon_tax1 * (12/44) * sum((state, ghg_gases),
greenhouse_gases(year, state, ghg_gases) * gwp(ghg_gases) )$(ord(year) > 1)
```

We allow two variations of the carbon taxes. The first code places a carbon tax on the level of GHG that bioenergy mitigates. The second puts a carbon tax plantation trees storing carbon. Since both bioenergy and plantations mitigate GHG, they are both negative and transform the carbon tax into a subsidy. The tax and price are imposed in 2020 and later by the $ sign.

```
- carbon_tax2 * (12 / 44) * sum((state, ghg_gases),
greenhouse_gases_re(year, state, ghg_gases) * gwp(ghg_gases) )
$(ord(year) > 1)

- carbon_credit * (12 / 44) * sum((state, ghg_gases),
greenhouse_gases_trees(year, state, ghg_gases)
* gwp(ghg_gases) )$(ord(year) > 1)
```

Equation 26 shows the Leontief processing costs for manufacturing plantation products. Plantation input (PI) takes the tree harvest and allocates them to a process. A process transforms the inputs into specific commodities. The plantation input keeps track of each plantation process (pp) in the state (s) at the time (t). The manufacturing costs (MC) is a vector of the marginal costs to convert raw inputs to finished products.

$$-\sum_{s}\sum_{pp} MC_{pp} \cdot PI_{t,s,pp} \tag{26}$$

MAPGEM also has Leontief production functions for crops. Equation 27 show the cost of the crop possibilities. The decision variable crops input (CI) allocates the harvest of crops to each processing crops (pc) for the state (s) and time (t). The marginal costs are held in the manufacturing crop cost (MCC) vector.

$$-\sum_{s}\sum_{pc} MCC_{pc} \cdot CI_{t,s,pc} \tag{27}$$

Equation 28 shows the Leontief production functions costs for renewable energy. This is the second method to account for renewable energy costs. The energy inputs (EI) transfers a raw material to produce energy (pe) for the state (s) and time (t). The vector, manufacture energy costs (MEC) holds the marginal cost for each renewable energy. We might add the decreasing production costs here too in the future.

$$-\sum_{s}\sum_{pe} MEC_{pe} \cdot EI_{t,s,pe} \tag{28}$$

The GAMS code for the three Leontief production functions costs is shown below.

```
- sum((state, processing_plantations), manufacture_cost(processing_plantations)
* plantation_inputs(year, state, processing_plantations) )

- sum((state, processing_crops), manufacture_crop_cost(processing_crops)
* crop_inputs(year, state, processing_crops) )

- sum((state, processing_energy), manufacture_energy_cost(processing_energy)
* energy_inputs(year, state, processing_energy) )
```

Equation 29 shows the growing costs for both plantations and crops. The growing costs exclude labor and fertilizer costs since the endogenous supply functions incorporate these costs. The crop costs (CC) matrix holds the marginal growing costs for each crop (c) in the state (s), while plantation costs (PC) has a similar matrix for the state (s) and plantation (p). The decision variable, cropland (CL), allocates land to each crop, while hectares (H) holds the land for each plantation type.

$$-\sum_{s}\sum_{c} CC_{s,c} \cdot CL_{t,s,c} - \sum_{s}\sum_{p} PC_{s,p} \cdot H_{t,s,p} \tag{29}$$

The GAMS code for both crop and plantation growing costs are below.

```
- sum((state, crops), crop_costs(state, crops) * cropland(year, state, crops) )

- sum((state, type), plantation_costs(state, type) * hectares(year, state, type) ) |
```

The last GAMS code imposes transportation costs to deliver bioelectricity, biodiesel, butanol, and ethanol to the markets located in the state.

```
-sum((state, renewable_energy), transport_charge(renewable_energy)
* market_distance(state, renewable_energy) * bioenergy(year, state, renewable_energy) ) ;
```

4.3 Transferring Commodities

We have three additional equations that do not fit neatly with the other chapters in the book. However, the equations deal with domestic consumption, exports, and imports. The first equation balances the domestic consumption, exports, imports, and domestic production. Equation 30 shows the supply must always exceed the demand for the commodity (i) at the time (t). The domestic demand and exports represent demands while imports and production represent supplies. We aggregate production over the states because the other decision variables reflect the national level. The commodity balance equation excludes the commodities transferred to the Leontief renewable energy production functions.

$$C_{t,i} + E_{t,i} \leq I_{t,i} + \sum_{s} P_{t,s,i} \tag{30}$$

The GAMS code for Equation 30.

```
commodity_balance(year, commodities)..

consumption(year, commodities) + exports(year, commodities) =l= imports(year, commodities)
+ sum(state, production(year, state, commodities) ) ;
```

The last two functions limit import and export quantities in Equations 31 and 32. The matrix, commodity quantities (CQ), holds the 2015 imports (I) and exports (E) for each commodity (i). The user defines the scalars for import and export constraints. For example, setting them to two prevents imports and exports from exceeding twice the imports and exports in 2015. From the Demand and Supply chapter, waste biomass and byproducts have a quantity of 0.1 for imports and exports because the calculation of parameters a_i, b_i, and c_i do not allow for zero quantities. Subtracting a 0.1 forces exports and imports for waste biomass to equal zero if the quantity does indeed equal 0.1.

$$I_{t,i} \leq import\ constraint \cdot (CQ_{i,I} - 0.1) \tag{31}$$

$$E_{t,i} \leq export\ constraint \cdot (CQ_{i,E} - 0.1) \tag{32}$$

The GAMS code for import and export constraints follows.

```
limit_imports(year, state, commodities)..

imports(year, commodities) =l= import_constraint
* ( commodity_quantities(commodities, 'imports') - 0.1 ) ;

limit_exports(year, state, commodities)..

exports(year, commodities) =l= export_constraint
* ( commodity_quantities(commodities, 'exports') - 0.1 ) ;
```

5 Crops

We discuss crops in this chapter along with the crop yield, Leontief production functions, growing costs, and GAMS code. Crops include banana, durian, kenaf, mango, papaya, pepper, pineapple, paddy, and rambutan.

5.1 Cropland and Yields

Land exists either as cropland and plantation land in MAPGEM. We discuss plantation land in the next chapter. Table 5.1 shows cropland in hectares by the state. Although trees require several years to reach maturity, we treat the trees as crops because MAPGEM calculates equilibrium market prices and quantities in five-year intervals. Consequently, producers can easily switch crops and trees within five years. Producers can harvest banana trees within 9 months. Durian trees take 4 or five years to harvest. Mango trees require 3 to 4 years to bear fruit if seedlings are started in a nursery. Papaya trees require 6 to 12 months. Peppers need 3 to 4 years to yield peppercorns. Pineapple takes 2 years. Rambutan trees are the only exception. They expect 5 to 6 years to harvest the rambutan fruits. Finally, kenaf is a fibrous plant similar to hemp and grows to maturity within a year. Kenaf is replacing tobacco and industries can make biocomposites for furniture parts and automobile cardboards [Kamal, 2014]. Producers can also produce paper, pulp, packing materials, and biofuel from kenaf [Taylor, 1995]. Kenaf contains enough protein for human and livestock consumption, but the food and livestock industries currently do not consume kenaf as a food [Kamal, 2014].

Table 5.2 shows the crop yield per state. Crop yield equals production in metric tons divided by total hectares. Malaysia experiences variations in crop yields, so we smooth crop yields by averaging between 2011 and 2015. We also compare the base year 2015 to the official production statistics. We adjusted yields to calibrate MAPGEM's production to correspond to the official 2015 production statistics. Consequently, mango, papaya, pepper, and pineapple use 2015 yields while paddy uses the average yield raised by 5%.

Table 5.2 has two caveats. First, the table includes the total production divided by total planted area. The total planted area includes immature and mature trees. It was difficult finding statistics on both types, so crop yields are based on total land dedicated to crops. We assume the ratio of immature to mature trees remains constant over time. Second, rice farmers grow paddy in two seasons: main and off-season. The government publishes total planted rice, which means a farmer can plant paddy multiple times during the year. We use parcel land to define the planting area. If we had used total planted, then MAPGEM would count some land twice. Rice yield is total production for both in season and off season divided by land parcel.

5.2 Leontief Production Functions for Crop Products

Table 5.3 shows the Leontief production functions for joint products from crop harvests. Currently, MAPGEM does not account for high-level processing. However, Leontief production functions determine how much waste biomass and byproducts the crops produce. The table excludes durian, kenaf, mango, papaya, pepper, and rambutan because these commodities are passed through and have production coefficients of one. We could expand MAPGEM to include waste biomass from these commodities, but we could not find these statistics. Currently, Malaysia does not grow sugarcane on a large scale. However,

Table 5.1: 2015 Cropland (hectares)

State	Banana	Durian	Kenaf	Mango	Papaya	Pepper	Pineapple	Paddy	Rambutan
Johor	10,396.10	15,051.50	50.00	131.60	1,411.10	129.70	6,357.30	1,286.47	1,890.40
Kedah	1,605.50	3,470.90	25.00	126.60	78.40	19.60	469.80	89,946.46	1,712.40
Kelantan	1,595.10	9,779.00	709.00	62.10	43.80	4.00	259.50	33,319.88	1,473.00
Melaka	900.20	1,586.10	13.00	302.10	187.10	12.80	8.80	1,127.45	449.90
Negeri Sembilan	548.00	2,323.20		105.70	26.30	1.00	177.50	895.11	919.20
Pahang	4,654.50	15,423.90	829.00	459.80	440.20	9.00	112.00	7,864.68	1,352.40
Penang	210.50	1,306.30	25.00	34.20	20.60	0.90	303.50	10,207.27	748.20
Perak	2,860.40	4,592.90	131.00	618.90	256.90	15.60	65.30	33,448.21	55.80
Perlis	26.80	279.30	50.00	1,619.20	3.50	0.30		22,325.11	293.90
Selangor	780.80	229.10	3.00	24.40	14.80	0.10	385.50	15,161.05	151.60
Terengganu	590.70	1,690.90	433.00	2.80	5.00	12.50	41.40	6,830.48	404.30
Sabah	2,878.40	4,379.50		1,111.50	166.10	35.90	941.80	15,535.67	1,670.80
Sarawak	3,539.90	10,484.20		1,160.10	184.00	16,092.00	1,724.60	52,989.15	5,641.60

Sources: Crop information for banana, durian, mango, papaya, pineapple, and rambutan came from Jabatan Pertanian Malaysia [2015]. Kenaf from Ministry of Plantation Industries and Commodities [2015c]. Pepper came from Ministry of Plantation Industries and Commodities [2015d]. Paddy from Ministry of Agriculture and Agro-Based Industry [2015]. The table, ag_land(state, crops), in MAPGEM contains the table information.

Table 5.2: Crop Yield, Averaged between 2011 and 2015 (metric tons per hectare)

State	Banana	Durian	Kenaf	Mango	Papaya	Pepper	Pineapple	Paddy	Rambutan
Johor	13.4617	4.8317		1.7576	26.3332	1.4647	30.9524	10.7456	3.4793
Kedah	7.4457	4.6634		3.5434	13.3520	1.4647	14.0732	10.8924	3.6884
Kelantan	9.8762	4.2192	5.4824	5.5395	17.7831	1.4647	16.8220	9.5934	3.9762
Melaka	9.1232	8.6186		4.7325	14.7290	1.4647	6.5795	8.8654	5.9171
Negeri Sembilan	9.6439	6.2193	0.5435	5.3765	18.8973	1.4647	34.9025	9.8910	4.6521
Pahang	8.1552	5.2166	7.1930	5.2240	9.7819	1.4647	19.3571	8.4517	4.0263
Penang	7.3189	4.3812	1.2595	2.4856	15.4126	1.4647	22.8570	14.2255	4.0229
Perak	9.3751	6.2516	0.8155	11.0047	27.1545	1.4647	32.8101	11.0823	4.9456
Perlis	14.3005	6.7152		2.5029	10.1143	1.4647		12.1524	4.6308
Selangor	5.3032	5.1228		9.6680	5.7500	1.4647	13.3616	15.5367	3.1868
Terengganu	5.2041	3.5326	3.6651	3.4286	6.1400	1.4647	17.1401	11.1227	4.0030
Sabah	15.9857	4.5505		3.3376	30.1240	0.0067	15.8760	8.3834	6.1011
Sarawak	7.7207	3.3947		1.7457	8.8755	1.7399	15.3697	4.9659	2.4304

Sources: Banana, durian, mango, papaya, pineapple, and rambutan derived from Jabatan Pertanian Malaysia [2011, 2012, 2013, 2014, 2015]. Kenaf from Ministry of Plantation Industries and Commodities [2015c]. Pepper from Ministry of Plantation Industries and Commodities [2015d]. Paddy from Ministry of Agriculture and Agro-Based Industry [2015]. The ag_yield(state, crops) in MAPGEM contains the crop yields.

sugarcane and bagasse are included for future expansion because Brazil, being a tropical country like Malaysia, manufactures ethanol from sugarcane on a large scale. Sugarcane could become an important future energy crop for Malaysia.

5.3 Growing Costs

Table 5.4 shows the itemized costs to grow crops per hectare of land. The table includes the growing costs of maintaining a farm. Malaysian agricultural sector has witnessed little growth to expand costs to establish a new farm [Economic Planning Unit, 2001]. Although the subtotal includes labor and fertilizer costs, we exclude labor and fertilizer costs from total costs. MAPGEM contains the inverse supply functions for both labor and fertilizer for each crop. A higher demand for fertilizer or labor costs would raise its costs. Finally, the producers' price index deflates all costs to 2015, the first year of the model.

5.4 GAMS Code and Mathematics

We add the total cropland for each state by summing over crops in Table 5.1. That way, GAMS automatically updates the land constraint if new crops are added to the table. Equation 33 shows total available land (AL) for each state (s). A refers to matrix A that contains land dedicated to crops (c) in hectares for each state (s).

$$AL_s = \sum_c A_{s,c} \tag{33}$$

The GAMS code below follows Equation 33.

```
avail_land(state) = sum(crops, ag_land(state, crops)) ;
```

We assume the available land remains constant, and producers do not switch cropland into plantations. However, we could modify the program to allow plantation owners to develop cropland into oil palm plantations. GAMS allocates land to maximize social welfare by growing crops. The total available land by state becomes the constraint. Meanwhile, cropland (CL) is the decision variable and determines how much land farmers dedicated to growing crops at time (t), state (s) and crop (c). Equation (34) shows the total land for growing crops must be equal to or less than the available land (AL) for each state (s).

$$\sum_c CL_{t,s,c} \leq AL_s \tag{34}$$

The GAMS code follows (34).

```
constraint_land(year, state)..

sum(crops, cropland(year, state, crops)) =l= avail_land(state);
```

Equations 35 - 36 restrict crop growing to match the 2015 statistics. It imposes a lower and upper bound to force farmers to grow on cropland (CL) to replicate the 2015 statistics. Users can change the

Table 5.3: Leontief Production Functions for Crop Products

Commodities	Banana	Durian	Kenaf	Mango	Papaya	Pepper	Pineapple	Paddy	Rambutan	Sugarcane
Banana	1.0000									
Banana residue	2.0000									
Durian		1.0000								
Kenaf			1.0000							
Mango				1.0000						
Papaya					1.0000					
Pepper						1.0000				
Pineapple							1.0000			
Pineapple waste							0.7000			
Rambutan									1.0000	
Rice								1.0000		
Rice husk								0.2200		
Rice straw								0.4000		
Sugar										
Sugarcane bagasse										0.3200

Sources: Bananas are from Jingura and Matengaifa [2008]. Pineapple wastes from Kroyer [1991]. Rice husk, rice straw, and sugarcane bagasse comes from Hashim [2005]. The manufacture_crop_output(crop_products, processing_crops) in MAPGEM contains the output possibilities for the crops. The vector, manufacture_crop_cost(processing_crops), holds the processing costs in MAPGEM while the manufacture_crop_input(crops, processing_crops) allocates the inputs to each process.

Table 5.4: Crop Growing Costs (RM per hectare per year)

Type	Banana	Durian	Kenaf	Mango	Papaya	Pepper	Pineapple	Paddy	Rambutan
Year	2010	2010	2016	2010		2005	2010	1993	2010
Budget based on years	3	20	10	15		10	1	1	20
Development Costs									
Land clearing	666.67	100.00		166.67			2,000.00		100.00
Drainage system	400.00	60.00		173.33			2,500.00		60.00
Land preparation	333.33	50.00		49.33			300.00	196.00	50.00
Storage		25.00					500.00		25.00
Irrigation system		450.00		720.00				14.21	450.00
Lining and planting	1,210.00	18.45						32.29	18.45
Farm road				240.00					
Fencing				109.67					
Input Costs									
Direct costs			5,575.00						
Equipment	833.33	18.00		301.00		2,928.00	500.00	95.57	140.00
Fertilizer	4,075.57	3,148.95		6,414.40		3,983.00	8,513.00	27.86	2,153.41
Fuel	1,260.00	455.00		1,200.00			200.00		455.00
Labor	4,946.67	2,087.25	567.93	11,947.87		10,644.50	4,990.00	379.39	2,076.75
Land tax/rent	500.00	500.00		500.00		500.00	500.00		500.00
Material Costs									
Miscellaneous			122.86					16.75	
Pesticide/Fungicide	685.33	264.96		725.68		818.90	60.00	83.86	142.16
Seedlings	938.67	33.83				480.00	7,920.00	68.14	33.83
Transport								69.43	
Weedicide	312.00	191.59		343.20		707.20	180.00	73.00	191.59
Plus 5%	808.08	370.15	313.29	1,144.56		1,003.08	1,416.45	52.83	319.81
Total	16,969.65	7,773.18	6,579.08	24,035.71		21,064.68	29,745.45	1,204.90	6,715.99
Minus fertilizer									
Minus labor									
Subtotal	7,947.41	2,536.97	6,011.15	5,673.43		6,437.18	16,242.45	797.65	2,485.83
Producer Price Index	0.9785	0.9785	0.9892	0.9785		0.8092	0.9785	0.5391	0.9785
Real costs 2015	8,122.03	2,592.71	6,076.78	5,798.09		7,954.99	16,599.34	1,479.60	2,540.45

Sources: Banana came from Anem [2010a]. Durian from Anem [2010b]. Kenaf from Abdelrhman et al. [2016]. Mango from Anem [2010c]. Pepper came from George et al. [2005]. Pineapple from Anem [2010d]. Rambutan from Anem [2010e]. Rice from Wah [1998]. Producer price index from Department of Statistics Malaysia [2014a]. The table, crop_costs(state, crops), in MAPGEM contains the crop costs.

scalar, land change, to allow GAMS to widen bounds over time. Land change is defined in percent per year. Meanwhile, the 5 in the exponent indicates five years.

$$CL_{t,s,c} \geq A_{s,c} \cdot \left(1 - \frac{land\ change}{100}\right)^{5t-0} \tag{35}$$

$$CL_{t,s,c} \leq A_{s,c} \cdot \left(1 + \frac{land\ change}{100}\right)^{5t-0} \tag{36}$$

The GAMS code, finally, follows 35 - 36.

```
constrain_crop_production1(year, state, crops)..

cropland(year, state, crops) =g= (1 - land_change / 100 )**(5*ord(year) - 0)
* ag_land(state, crops) ;

constrain_crop_production2(year, state, crops)..

cropland(year, state, crops) =l= (1 + land_change / 100 )**(5*ord(year) - 0)
* ag_land(state, crops);
```

Leontief production functions require two sets of equations: Input and Output. Equation 37 calculates how much producers harvest from crops. The decision variable, cropland (CL), determines how much land is dedicated to each crop (c) at the time (t) in the state (s). Then crop harvests equal cropland multiplied by agricultural yield (AY). Crops yields can increase over time in percent, which crop growth specifies. The decision variable, crop inputs (CI), allocates each crop (c) to its processing crops (pc) to manufacture specific commodities. Processing crop allows multiple products for each crop and ensures total crop usage equals its supply. The matrix manufacture crops input (MCI) holds the input coefficients for each process.

$$\sum_{pc} MCI_{c,pc} \cdot cropinputs_{t,s,pc} \leq AY_{s,c} \cdot CL_{t,s,c} \cdot \left(1 + \frac{crop\ growth}{100}\right)^{5t-5} \tag{37}$$

The GAMS code below shows the input for production possibilities.

```
balance_crop_inputs(year, state, crops)..

sum(processing_crops, manufacture_crop_input(crops, processing_crops)
* crop_inputs(year, state, processing_crops) ) =l= ag_yield(state, crops)
* cropland(year, state, crops) * ( 1 + crop_yield_growth / 100 )
**(5*ord(year) - 5) ;
```

The second equation for Leontief production functions in 38 connects the crop input (CI) for each process crop (pc) to its output. The matrix manufacture crop output (MCO) contains the production coefficients for each process. The subscript, crop products (cp), is a subset of all products in MAPGEM that farmers and producers export or sell to Malaysians. That way, we can separate plantation products from crop products. Furthermore, Leontief production functions in 38 usually have a greater than or equal sign. However, the equal sign forces the production of waste biomass and byproducts. Otherwise, the production function would not produce waste biomass for a carbon tax. Finally, the crop products (cp) can be supplied to production (P), where farmers move products to domestic and export demands or transfer the products to the Leontief renewable energy production function via the transfer (T) decision variable.

$$\sum_{pc} MCO_{cp,pc} \cdot CI_{t,s,pc} = P_{t,s,cp} + T_{t,s,cp} \tag{38}$$

The GAMS code for the output for production possibilities is below:

```
balance_crop_outputs(year, state, crop_products)..

sum(processing_crops, manufacture_crop_output(crop_products, processing_crops)
* crop_inputs(year, state, processing_crops)) =e=
production(year, state, crop_products) + transfer(year, state,
crop_products) ;
```

6 Plantations

In this section, we cover the plantation trees, plantation costs, and the commodities manufactured from plantations. The plantations include cocoa, coconut, oil palm, rainforest, and rubber. The mathematics and GAMS code comes at the end.

6.1 Plantation Trees

The plantations are treated as dynamic equations because the oil palm plantations have traditionally taken land away from cocoa, coconut, rainforests, and rubber [Basiron and Weng, 2004]. We begin with the tree inventory in Table 6.1. Only the oil palm trees have three growth phases while the other trees just have one. Consequently, coconut, cocoa, and rubber trees contain both mature and immature trees. The plantation owners replace the mature trees with new ones to maintain the high yields. Hence, the harvest yield and growing costs cover both newly planted and mature trees. Furthermore, farmers can harvest coconut trees between six and ten years after planting and attain peak harvests between 15 and 20 years. Cocoa trees mature much quicker, and farmers can harvest after 3-5 years. Subsequently, plantation owners can tap five-year-old rubber trees and older. The rubber estates account for 79,238 hectares and are allocated proportionally to the small landholders by state level since we have the statistics for small land holders. We utilize 2016 rubber statistics because of the unavailability of 2015.

The oil palm trees comprise the largest land use in agriculture after rainforests. Malaysia is the world's second largest producer of palm oil products after Indonesia [Crutchfield, 2007]. Meanwhile, Thailand and Nigeria come third and fourth [Crutchfield, 2007]. Because of the importance of the oil palms, MAPGEM contains three types of palm oil trees that reflect a trees' age: Newly planted, five-year-old, and mature. We follow this construction because the different growth phases impart different costs, GHG emissions, and fertilizer application. Although Table 6.1 does not show newly planted oil palms, MAPGEM allocates new land in 2015.

Table 6.1 does not show forest. The model aggregates over rainforest types in Table 6.2 and inserts the total for the state in Table 6.1. The division could become important later when more information becomes available such as landowners converting peat swamps into oil palm plantations. Nevertheless, the state data shows discrepancies with the national data. For example, the Ministry Of Natural Resources and Environment Malaysia, [2011] indicates that Malaysia has 18.3 million hectares of forests while Table 6.2 sums to 21 million hectares. The discrepancy originates from Sarawak.

Table 6.3 shows the plantation yield in tonnes per hectare. Harvesters obtain latex from rubber trees, coconuts from coconut trees, cocoa beans from cocoa trees, and fresh fruit bunches (FFB) from oil palm trees. On the other hand, the rainforests provide no harvests. The importance of the forest lies in their carbon sinks of GHG and potential carbon credits. Moreover, the yields come from the literature with adjustments. For instance, cocoa utilizes the 2015 yields to calibrate the production to 2015 statistics while the average yields for coconut and rubber are raised by 5% for calibration. The average smooths year to year fluctuations in yields. The ten-year-old oil palms originate from the Malaysia Palm Oil Board. The FFB yields hold steady up to 25 years of age. On the other hand, the five-year-old palm trees yield approximately 0.5385 of the FFB of mature trees [Michael, 2012]. Finally, newly planted oil palms yield zero FFB. At this time, MAPGEM does not account for declining FFB yields of older oil palm trees. Instead, we assume the age distribution is uniform for oil palms, and the palm oil industry follows sustainable practices. Landowners cut down 1/30 hectares of old palm trees and replant with new ones. Subsequently, the palm oil mills can utilize the waste biomass from the oil palm trunks.

Table 6.1: 2015 Plantation Tree Inventory (hectares)

state	Cocoa Trees	Coconut Trees	Forest	Oil Palm 0y	Oil Palm 5y	Oil Palm 10y	Rubber Trees
Johor	360.18	11,550.00		0.00	73,788.00	665,795.00	38,248.70
Kedah	56.50	1,931.00		0.00	5,339.00	81,905.00	76,322.28
Kelantan	580.27	8,078.00		0.00	45,659.00	106,314.00	95,718.09
Melaka	22.34	2,451.00		0.00	4,331.00	50,272.00	14,499.34
Negeri Sembilan	73.69	1,576.00		0.00	25,720.00	152,021.00	51,670.08
Pahang	1,359.48	3,988.00		0.00	98,029.00	627,210.00	78,060.34
Penang	27.58	51.00		0.00	790.00	13,657.00	1,438.94
Perak	822.49	9,446.00		0.00	48,241.00	350,073.00	43,683.73
Perlis	20.40	370.00		0.00	7.00	287.00	8,650.18
Selangor	97.78	9,721.00		0.00	11,018.00	126,318.00	6,238.79
Terengganu	26.68	1,964.00		0.00	31,178.00	141,409.00	30,333.93
Sabah	6,847.00	16,481.00		0.00	168,994.00	1,375,229.00	115,058.74
Sarawak	6,949.00	14,222.00		0.00	270,452.00	1,168,907.00	266,947.19

Sources: Cocoa comes from Ministry of Plantation Industries and Commodities [2015b]. Coconut from Ministry of Agriculture and Agro-Based Industry [2015]. Palm oil from Economics & Industry Development Division [2015b]. Rubber from Ghani [2017]. The plantation_2015(state, type) holds the 2015 tree inventory in MAPGEM.

Table 6.2: 2015 Forest Type (hectares)

	Inland Forest	Peat Swamp	Mangrove	Forest Plantation
Johor	318,727	3,796	31,915	60,199
Kedah	326,192	0	6,201	9,583
Kelantan	460,212	0	0	163,637
Melaka	5,002	0	102	0
Negeri Sembilan	152,607	0	101	3,000
Pahang	1,340,300	140,830	2,416	80,447
Penang	5,015	0	1,045	0
Perak	899,107	0	43,878	56,503
Perlis	10,128	0	0	671
Selangor	136,860	82,890	18,998	11,381
Terengganu	514,136	25,931	1,037	3,833
Sabah	3,650,000	120,000	378,000	287,000
Sarawak	6,506,900	654,600	105,500	4,352,000

Sources: Forest type in peninsula came from Forestry Department Peninsular Malaysia [2015]. Sabah forest data from Department of Statistics Malaysia [2016b]. Sarawak data from Department of Statistics Malaysia [2016c]. The forest_type_2015(state, forest_type) contains the forest type in MAPGEM. The forest type is summed for each state and added to the 2015 tree inventory.

Table 6.3: Average Plantation Yields by State (metric tons per hectare)

State	Cocoa Trees	Coconut Trees	Forest	Oil Palm 0y	Oil Palm 5y	Oil Palm 10y	Rubber Trees
Johor	0.2086	7.2709	0.0000	0.0000	10.5288	19.5520	0.8553
Kedah	0.2086	5.7518	0.0000	0.0000	10.4857	19.4720	0.8553
Kelantan	0.2086	6.6092	0.0000	0.0000	6.4771	12.0280	0.8553
Melaka	0.2086	7.6328	0.0000	0.0000	11.8944	22.0880	0.8553
Negeri Sembilan	0.2086	11.2327	0.0000	0.0000	10.2983	19.1240	0.8553
Pahang	0.2086	6.2533	0.0000	0.0000	10.1238	18.8000	0.8553
Penang	0.2086	7.3292	0.0000	0.0000	8.5977	15.9660	0.8553
Perak	0.2086	13.8974	0.0000	0.0000	11.2525	20.8960	0.8553
Perlis	0.2086	6.0457	0.0000	0.0000	9.8859	18.3583	0.8553
Selangor	0.2086	13.497	0.0000	0.0000	10.8454	20.1400	0.8553
Terengganu	0.2086	3.0964	0.0000	0.0000	8.0129	14.8800	0.8553
Sabah	0.0970	3.3437	0.0000	0.0000	11.2999	20.9840	0.8553
Sarawak	0.0497	2.6558	0.0000	0.0000	8.8152	16.3700	0.8553

Source: Cocoa derived from data from the Ministry of Plantation Industries and Commodities [2015a,b]. Coconut derived from Ministry of Agriculture and Agro-Based Industry [2015]. Fresh fruit bunch (FFB) comes from Economics & Industry Development Division [2015a]. Rubber from Ghani [2017]. The plantation_yield(state, type) holds the plantation yields in MAPGEM.

Table 6.4 shows the maximum land transfer that oil palm plantations can take away from cocoa, coconut, rainforests, and rubber. We assume the expanding oil palm plantations are a concave function where oil palms increase at a decreasing rate. The decrease corresponds to a half every twenty years, which comes from historical oil palm data. Consequently, the land transfers decrease by $e^{-0.0347(5(t-1))}$ every five years. The three growth phases of oil palms equal zero since oil palm cannot take land away from itself. Although producers have transferred less land in recent years, oil palm plantation owners can take up to 10% of the land away from cocoa, coconut, and rubber. Finally, we average the oil palm hectares for both five year and ten year. We multiply by five (for five years) and deduct the land transfers from cocoa, coconut, and rubber. The remainder is reserved for rainforest land transfers.

6.2 Plantation Costs

Table 6.5 shows the itemized costs for growing trees on plantations per year. In the table, the number of years indicates the time span that the budget is based on because several costs come in phases during a tree's life cycle. The costs include clearing the land, preparing the land for seedlings, and costs covering the entire growing cycle of the trees. Some items such as fuel have no entries. We leave these items in the table for future refinements as data becomes available. Subsequently, forests entail no costs, but we include it to complete the table. Some trees have different cost cycles. For example, the cost of rubber trees is based on a maintenance cycle. However, we could base the costs on building a new rubber plantation but the costs differ by a little. (Rubber trees have an economic life of 32 years). Subsequently, the oil palm trees have different growing cycles based on age: Newly planted, five-year-old, and mature oil palms. Furthermore, we deduct the labor and fertilizer costs since the endogenous supply functions of labor and fertilizer handle the prices of these resources. Finally, all costs are in Malaysian ringgits, and we deflate the cost to 2015 using the producer price index.

Table 6.4: Maximum Land Transfers to Oil Palm Plantations

State	Cocoa Trees	Coconut Trees	Forest	Oil Palm 0y	Oil Palm 5y	Oil Palm 10y	Rubber Trees
Johor	36.02	1,313.40	17,010.71				3,824.87
Kedah	5.65	108.80	958.32				7,632.23
Kelantan	58.03	539.40	9,088.76				9,571.81
Melaka	2.23	253.50	1,547.33				1,449.93
Negeri Sembilan	7.37	153.20	8,051.42				5,167.01
Pahang	135.95	375.40	28,055.62				7,806.03
Penang	2.76	181.00	524.35				143.89
Perak	82.25	938.40	10,397.98				4,368.37
Perlis	2.04	53.00	61.00				865.02
Selangor	9.78	951.90	6,750.44				623.88
Terengganu	2.67	451.10	3,013.84				3,033.39
Sabah	684.75	1,678.50	120,677.88				11,505.87
Sarawak	694.86	1,422.60	491,128.82				26,694.72

Note: We calculate the average of the change in total oil palm plantations by state between 2011 and 2015. We multiply by five for five years and deduct the land transfers from cocoa, coconut, and rubber. The remaining land is allocated rainforests. The calculation causes Perlis to have a negative land transfer. Instead, we use the maximum land transfer in lieu for rainforests. The transfer_land(states, type) holds the maximum land transfer for plantations in MAPGEM.

6.3 Leontief Production Functions for Plantation Products

Table 6.6 shows the Leontief production functions for plantation products. MAPGEM passes cocoa and latex through the production possibilities matrix because these products produce no byproducts. On the other hand, coconut trees produce coconuts and coconut husks while producers harvest fresh fruit bunches (FFB) from oil palms and manufacture a broad range of products. Table 6.6 has three production possibilities for palm oil. Producers can produce palm oil, convert palm oil into palm biodiesel, or collect yellow grease. We assume all domestically consumed palm oil returns as yellow grease from recycling frying oil from the food industry. However, MAPGEM imposes a quantity restriction on yellow grease to correspond to how much industry can collect. From Kheang et al. [2006], Malaysia disposed of 50,000 tons of yellow grease in 2006. We utilized MAPGEM to find the percentage of yellow grease and palm oil consumption to yield 50,000 tons, which equals 1.88% of domestically consumed palm oil. Finally, we assume landowners cut down 1/30th of their mature oil palm trees and replant with new ones. Then mills could utilize the biomass from the oil palm trunks.

MAPGEM estimates that 97% of the waste biomass originate from the oil palm plantations. Thus, the palm oil mills would lie at the center of renewable energy. The Chapter of Renewable Energy contains the operating and capital costs of the palm oil mills, and include the manufacturing of renewable energy. Furthermore, the chapter shows the derivation of the production coefficients of palm biodiesel. The chapter also deals with methane emitted from the palm oil mill effluent (POME). The palm oil mills can collect methane as a byproduct to generate bioelectricity or flare methane to reduce its global warming potential.

6.4 GAMS Code and Mathematics

Equations 39- 43 handle the oil palm plantations. Equation 39 sets the upper limit of transferring land (TL) from cocoa, coconut, rainforest, and rubber. Convert (CN) is a decision variable that depends

Table 6.5: Plantation Cost (RM per hectare)

Items	Cocoa	Coconut	Forest	Oil Palm 0y	Oil Palm 5y	Oil Palm Mature	Rubber
Year	2004	2015		2008	2008	2008	2009
Number of Years	25	25		25	25	25	5
Develop land		620.00		4,000.00 - 5,500.00			176.00
Drainage							23.00
Equipment							243.00
Farm road							116.00
Fertilizer	1,000.00				2,248.00	2,248.00	
Upkeep & cultivation					350.00	350.00	
Fuel							
Fungicide							
Harvesting					522.00	522.00	
Labor	1,400.00	1,936.00					1,143.08
Land tax/rent		500.00			500.00	500.00	500.00
Miscellaneous					657.00	657.00	240.00
Overhead	500.00						
Pesticides							245.40
Planting							236.00
Seedlings		160.00					
Transportation					535.00	535.00	
Weedicide							54.00
Plus 5%		160.80			240.60	240.60	143.02
Total	2,900.00	3,376.80		4,000.00 - 5,500.00	5,052.60	5,052.60	3,003.50
Minus fertilizer							
Minus labor							
Total	500.00	1,440.80		4,000.00 - 5,500.00	2,804.60	2,804.60	1,860.42
Producer Price Index	0.7544	100.00		1.0186	1.0186	1.0186	0.9080
Real Cost 2015	662.78	,1,440.80		3,926.96 - 5,399.57	2,753.39	2,753.39	2,048.92

References: Cocoa information came from Azhar and Lee [2004]. Coconut from Michael [2015]. Palm oil from Oh [2011]. Rubber from Malaysian Rubber Board [2009]. Producer price index from Department of Statistics Malaysia [2014a]. In the case of a range of values, we use the average as the cost parameter. The plantation_costs(state, type) in MAPGEM contains the cost to maintain a plantation.

Table 6.6: Leontief Production Functions for Plantation Products

Type	Cocoa Cocoa bean	Coconut Coconut	Palm Oil FFB	Palm Biodiesel FFB	Yellow Grease FFB	Rubber Latex
Cocoa bean	1.00000					
Coconut		1.00000				
Coconut husk		0.34000				
FFB			1.00000	1.00000	1.00000	
EFB			0.22000	0.22000	0.22000	
Latex						1.00000
Methane			0.00646	0.00646	0.00646	
Palm biodiesel			0.00000	0.18870	0.00000	
Palm fiber			0.13500	0.13500	0.13500	
Palm frond			0.57200	0.57200	0.57200	
Palm kernel cake			0.03480	0.03480	0.03480	
Palm kernel oil			0.02520	0.02520	0.02520	
Palm oil			0.20000	0.00000	0.20000	
Palm shell			0.05500	0.05500	0.05500	
Palm trunk			0.01462	0.01462	0.01462	
PFAD			0.01000	0.01000	0.01000	
POME			0.49276	0.49276	0.49276	
Yellow Grease			0.00000	0.00000	0.20000	

Sources: Coconut husks, palm fronds, and palm oil from Goh et al. [2010]. EFB, palm fiber, and palm shells from Yusoff [2006]. Methane and POME derived from Yacob et al. [2006]. Palm kernel oil and palm kernel cake from Wood and Corley [1993]. PFAD derived from Zero and Rainforest Foundation Norway [2016]. Palm trunks are derived from Elbersen et al. [2005] and equal 0.4385 wet metric tons per FFB. Then we divide by 30 for the average yield. The manufacture_output(plantation_products, processing_plantations) holds the output possibilities in MAPGEM. The input possibilities is manufacture_input(type, processing_plantations) that assigns a harvest to a process.

on time (t), state (s), and plantation type (p). The convert (CN) determines how much land oil palm plantations take from the other land sources. The decreasing growth (δ_t) assumes the planted hectares of oil palm trees declines in half every twenty years. Hectares (H), a decision variable, holds the total hectares for each plantation (p) type over time (t) and state (s). Equation 40 sums the total new land transferred to oil palm plantations 0y for each state (s) and time (t) and also includes the replanted trees (RT) from the mature oil palms. Equation 41 has two parts for five-year-old palm plantations. The first part transfers land from oil palms 0y into oil palms 5y. Furthermore, the model starts in 2015, so the model loads the current new trees for time t = 1 in the year 2015. The ϕ is an indicator function and serves as an on-off switch. The matrix plantation (PL) contains the 2015 tree inventory. Then Equation'42 holds the mature oil palms and equals the mature oil palm trees from the last time period plus the five-year-old oil palms from the last period. For the year 2015 (t=1), the indicator function loads the 2015 inventory of trees from matrix plantation (PL). At last, Equation 43 handles the replanting of oil palms. It takes $\frac{1}{30}$ of the mature oil palms and transfers the land into newly planted.

$$CN_{p,s,t} \leq \delta_t TL_{s,p} \tag{39}$$

$$H_{oil\ palm\ 0y,s,t} = \sum_p CN_{p,s,t} + RT_{s,t} \tag{40}$$

$$H_{oil\ palm\ 5y,s,t} = H_{oil\ palm\ 0y,s,t-1} \cdot \phi\,(t > 1) + PL_{oil\ palm\ 5y,s} \cdot \phi\,(t = 1) \tag{41}$$

$$\begin{aligned} H_{oil\ palm\ 10y,s,t} =& H_{oil\ palm\ 10y,s,t-1} \cdot \phi\,(t > 1) + H_{oil\ palm\ 5y,s,t-1} \cdot \phi\,(t > 1) \\ &+ RT_{s,t} + PL_{s,oil\ palm\ 10y} \cdot \phi\,(t = 1) \end{aligned} \tag{42}$$

$$RT_{s,t} = \frac{1}{30} \cdot H_{oil\ palm\ 10y,s,t} \tag{43}$$

The GAMS code shows Equations 39- 43 in order.

```
change_land_use(year, state, type)..

convert(year, state, type) =l= decreasing_growth(year) * transfer_land(state, type) ;

new_oil_palms(year, state)..

hectares(year, state, 'oil_palm_0y') =e= sum(type, convert(year, state, type) )
+ replant_tree(year, state);

immature_trees(year, state)..

hectares(year, state, 'oil_palm_5y') =e= hectares(year - 1, state, 'oil_palm_0y')
$(ord(year) > 1)+ plantation_2015(state, 'oil_palm_5y')$(ord(year) = 1) ;

palm_oil_plantations(year, state)..

hectares(year, state, 'oil_palm_10y') =e= hectares(year - 1, state, 'oil_palm_10y')
$(ord(year) > 1) + hectares(year - 1, state, 'oil_palm_5y')$(ord(year) > 1)
- replant_tree(year, state)
+ plantation_2015(state, 'oil_palm_10y')$(ord(year) = 1) ;

replant_oil_palm(year, state)..
```

```
replant_tree(year, state) =e= ( 1 / 30 ) * hectares(year, state, 'oil_palm_10y') ;
```

Equations 44 - 47 share a similar construction. The current land for cocoa, for example, equals the land for cocoa from the last period minus the loss of converted (CN) land to oil palms. The $\phi()$ is an indicator function and serves as an on-off switch. The land conversion delays one time period to allow producers to harvest the trees before clearing the land. For 2015, the condition statement loads the 2015 tree inventory held in the plantation (PL) matrix.

$$H_{cocoa,s,t} = H_{cocoa,s,t-1} \cdot \phi\left(t > 1\right) - CN_{cocoa,s,t-1} \cdot \phi\left(t > 1\right) + PL_{cocoa,s} \cdot \phi\left(t = 1\right) \tag{44}$$

$$H_{coconut,s,t} = H_{coconut,s,t-1} \cdot \phi\left(t > 1\right) - CN_{coconut,s,t-1} \cdot \phi\left(t > 1\right) + PL_{coconut,s} \cdot \phi\left(t = 1\right) \tag{45}$$

$$H_{forest,s,t} = H_{forest,s,t-1} \cdot \phi\left(t > 1\right) - CN_{forest,s,t-1} \cdot \phi\left(t > 1\right) + PL_{forest,s} \cdot \phi\left(t = 1\right) \tag{46}$$

$$H_{rubber,s,t} = H_{rubber,s,t-1} \cdot \phi\left(t > 1\right) - CN_{rubber,s,t-1} \cdot \phi\left(t > 1\right) + PL_{rubber,s} \cdot \phi\left(t = 1\right) \tag{47}$$

The GAMS code to keep track of cocoa, coconut, forest, and rubber trees is below.

```
cocoa_plantations(year, state)..

hectares(year, state, 'cocoa_trees') =e= hectares(year - 1, state, 'cocoa_trees')
$(ord(year) > 1) + plantation_2015(state, 'cocoa_trees')$(ord(year) = 1)
- convert(year - 1, state, 'cocoa_trees')$(ord(year) > 1) ;

coconut_plantations(year, state)..

hectares(year, state, 'coconut_trees') =e= hectares(year - 1, state, 'coconut_trees')
$(ord(year) > 1) + plantation_2015(state, 'coconut_trees')$(ord(year) = 1)
- convert(year - 1, state, 'coconut_trees')$(ord(year) > 1) ;

pristine_forest(year, state)..

hectares(year, state, 'forest') =e= hectares(year - 1, state, 'forest')
$(ord(year) > 1) + total_forest_2015(state)$(ord(year) = 1)
- convert(year - 1, state, 'forest')$(ord(year) > 1) ;

rubber_plantations(year, state)..

hectares(year, state, 'rubber_trees') =e= hectares(year - 1, state, 'rubber_trees')
$(ord(year) > 1) + plantation_2015(state, 'rubber_trees')$(ord(year) = 1)
- convert(year - 1, state, 'rubber_trees')$(ord(year) > 1) ;
```

Equations 48 - 49 show the multi-input and output Leontief production functions to convert harvest of the plantations into products that Malaysians can consume or export. Production possibilities require two equations: input and output. The input equation takes the trees in hectares (H) and multiplies it by the plantation yield (PY). Meanwhile, the combined (COM) matrix combines the harvests from the oil palms 5y and oil palms 10y. The combined matrix has two subscripts that refer to the plantation type (p) with p_1 being an alias. The matrix, manufacture input (MI) holds the production input coefficients for each process (process). The decision variable, plantation inputs (PI), allocates the plantation harvest to each process.

$$\sum_{process} MI_{p,process} \cdot PI_{process,s,t} \leq \sum_{p_1} COM_{p,p_1} \cdot PY_{s,p_1} \cdot H_{p_1,s,t} \tag{48}$$

Equation 49 takes the plantation inputs (PI) and manufactures products and byproducts as outputs. The matrix, manufacture output (MO) holds the output production coefficients. Normally, a production function uses a greater than or equal sign. However, the equality forces MAPGEM to produce byproducts. Otherwise, producers would not produce byproducts and wastes if producers must pay a carbon tax on byproducts. Subsequently, MAPGEM transfers the output to two streams. The production (P) stream directs commodity flows to domestic and export demands while the transfer(T) variable transfers the agricultural wastes and byproducts to the renewable energy Leontief production functions. In the equations, the production and transfer have subscripts time (t), state (s), and commodity. However, the code replaces the commodity subscript with a subset, called plantation products (pp). That way, the manufacturing possibilities restricts products relevant to the plantation industries and not all the commodities in MAPGEM.

$$\sum_{process} MO_{pp,process} \cdot PI_{process,s,t} = P_{pp,s,t} + T_{pp,s,t} \tag{49}$$

The GAMS code for the output production possibilities is below.

```
balance_inputs(year, state, type)..

sum(processing_plantations, manufacture_input(type, processing_plantations)
* plantation_inputs(year, state, processing_plantations)) =l=
sum(type1, combine(type, type1) * plantation_yield(state, type1)
* hectares(year, state, type1) ) ;

balance_outputs(year, state, plantation_products)..

sum(processing_plantations, manufacture_output(plantation_products,
processing_plantations) * plantation_inputs(year, state, processing_plantations))
=e= production(year, state, plantation_products)
+ transfer(year, state, plantation_products) ;
```

Equation 50 imposes a unique constraint on the model. One of the processes of the Leontief production function allows the collection of yellow grease. We assume that domestically consumed palm oil could return as yellow grease from the frying food. Furthermore, the yellow grease process adds a collection cost. The constraint in Equation 50 imposes a quantity restriction, so total grease produced in Malaysia equals 50,000 metric tons, which equals 1.88% of the Malaysian palm oil consumption (C). Once the industry collects the yellow grease, producers can ship the grease to the domestic and export markets via the production (P) decision variable or through the transfer (T) variable for renewable energy. Note, the production and transfer variables occur at the state (s) level while consumption occurs at the national level.

$$\sum_{s} (P_{yellow\ grease,s,t} + T_{yellow\ grease,s,t}) \leq 0.0188 \cdot C_{palm\ oil,t} \tag{50}$$

The GAMS code for the yellow grease constraint is below.

```
yellow_grease_constraint(year)..

sum(state, production(year, state, 'yellow_grease') + transfer(year, state, 'yellow_grease'))
=l= 0.0188 * consumption(year, 'palm_oil') ;
```

7 Renewable Energy

Renewable energy covers nine sections. The first section forecasts petrol, diesel, and bioelectricity usage between 2020 and 2070. The forecasts allow the comparison between renewable energy and fossil fuel use. Then we derive the production coefficients for biodiesel, bioelectricity, bioethanol, and biobutanol in Sections (2) - (5). Section (6) shows the derivation of the production constraints, in case, users want to impose a growth constraint on renewable energy. Section (7) estimates the operating and capital costs to manufacture renewable energy while Section (8) estimates the transportation cost to deliver the renewable energy to the market. Finally, the author connects the production and cost coefficients to the GAMS code.

7.1 Future Fossil Fuel Use

Table 7.1 shows Malaysians' energy consumption of petrol, diesel, and electricity. The per capita energy usage comes from Malaysian Energy Commission [2015] that reports petrol and diesel in kilotons of oil equivalent (KTOE). We convert petrol into liters per capita by dividing the population and conversion factor, $1m^3 petrol = 0.86TOE$. Similarly, we convert diesel into liters per capita by dividing by the population and the conversion factor, $1m^3 diesel = 0.98TOE$. Also, a thousand liters equal to one cubic meter, or m^3. Finally, the Malaysian Energy Commission [2015] provides electricity usage per capita. Subsequently, a trend regression estimates the per capita energy usage for 2015. We maintain a conservative energy forecast because the per capita energy usage remains constant in the future. We expect the per capita energy usage would continue to rise as Malaysia develops. However, we do not know the per capita energy usage changes over time. Finally, MAPGEM forecasts total energy usage by multiplying the energy usage per capita by the forecasted population of Malaysia.

7.2 Biodiesel Production

Palm oil mills can manufacture biodiesel from palm oil, PFAD, and yellow grease. People and industries use palm oil in a variety of food, soap, and cosmetic products. Meanwhile, PFAD is the byproduct of refining palm oil as the mills remove about 5% of the free fatty acids from palm oil [Cheah et al., 2010, Zero and Rainforest Foundation Norway, 2016]. Although PFAD is a byproduct, palm oil mills export the PFAD or sell the PFAD to the animal feed industries, and soap and oleochemical industries [Zero and Rainforest Foundation Norway, 2016]. Although the chemical industry extracts Vitamin E from PFAD [Cheah et al., 2010], we exclude Vitamin E from the model. Finally, Malaysian industries can also convert yellow grease into biodiesel. Malaysia produces about 50,000 tons of yellow grease per year [Kheang et al., 2006].

Table 7.2 shows the biodiesel production coefficients for the renewable energy Leontief production function. The table links the source of biodiesel in one ton of feedstock to the amount of biodiesel produced in tons and liters. The Leontief renewable energy production function passes palm biodiesel through with no processing because the mills produce palm biodiesel in the plantations Leontief production function. Since the input feedstock is expressed in tons of biodiesel, the output converts the weight into the volume by multiplying 1,000 kg in a ton and dividing by its density. Furthermore, the Leontief production function takes the PFAD as an input in tons and convert it into biodiesel. The conversion converts 80% of the palmitic free fatty acid into biodiesel because PFAD contains high levels of free fatty acids. PFAD contains approximately 86.4% palmitic acid Cheah et al. [2010] and yield 0.6934 tons of biodiesel from one ton of

Table 7.1: Malaysia Energy Usage

	Levels			Per Capita		
Year	Population	Petrol (KTOE)	Diesel (KTOE)	Petrol (liters)	Diesel (liters)	Electricity (kWh)
1990	18,102.40	2,901.00	4,421.00	186.3430	249.2059	1,101
1991	18,547.20	3,135.00	4,873.00	196.5444	268.0970	1,178
1992	19,067.50	3,326.00	5,291.00	202.8290	283.1509	1,358
1993	19,601.50	3,666.00	5,339.00	217.4727	277.9358	1,460
1994	20,141.70	4,139.00	5,643.00	238.9466	285.8827	1,700
1995	20,681.80	4,548.00	5,810.00	255.7017	286.6565	1,902
1996	21,222.60	5,205.00	6,735.00	285.1830	323.8269	2,080
1997	21,769.30	5,586.00	7,314.00	298.3720	342.8344	2,359
1998	22,333.50	5,854.00	6,252.00	304.7877	285.6512	2,406
1999	22,909.50	6,793.00	6,506.00	344.7844	289.7826	2,472
2000	23,494.90	6,387.00	7,627.00	316.1003	331.2486	2,603
2001	24,030.50	6,827.00	8,116.00	330.3457	344.6301	2,695
2002	24,542.50	6,948.00	8,042.00	329.1869	334.3638	2,783
2003	25,038.10	7,360.00	8,539.00	341.8047	348.0003	2,898
2004	25,541.50	7,839.00	9,262.00	356.8747	370.0261	2,980
2005	26,045.50	8,211.00	8,672.00	366.5767	339.7508	3,048
2006	26,549.90	7,518.00	8,540.00	329.2615	328.2229	3,150
2007	27,058.40	8,600.00	9,512.00	369.5710	358.7101	3,285
2008	27,567.60	8,842.00	9,167.00	372.9521	339.3143	3,370
2009	28,081.50	8,766.00	8,634.00	362.9800	313.7369	3,452
2010	28,588.60	9,560.00	8,388.00	388.8361	299.3915	3,700
2011	29,062.00	8,155.00	8,712.00	326.2872	305.8907	3,706
2012	29,510.00	10,843.00	9,410.00	427.2497	325.3826	3,966
2013	30,213.70	12,656.00	9,568.00	487.0731	323.1403	4,110
				Forecast	Forecast	Forecast
2014				462.3	348.6	4,769.8
2015				477.4	351.6	5,023.8

Malaysian Energy Commission [2015] provides the total diesel, petrol, and electricity consumption. Trend regression predicts the energy consumption per capita for 2014 and 2015. The 2015 per capita is entered into energy_per_capita(fossil_energy) in MAPGEM. Then the estimated energy usage equals the Malaysian population projection multiplied by the per capita energy usage.

Table 7.2: Biodiesel Production Coefficients

Item	units	Palm Biodiesel	PFAD Biodiesel	Yellow Grease Biodiesel
Palm oil	ton	0.9434		
PFAD	ton		0.6912	
Yellow grease	ton			0.8000
Biodiesel density (kg / liter)	kg/l	0.8750	0.8750	0.8750
Biodiesel	liters	1,142.86 liters	789.94 liters	914.29 liters

Sources: Conversion of crude palm oil into biodiesel comes from Hassan et al. [2011]. Yellow grease from Kheang et al. [2006]. The palm biodiesel production coefficients are entered into manufacture_output(plantation_products, processing_plantations) in MAPGEM. Meanwhile, manufacture_energy_output(processing_energy, renewable_energy) hold the yellow grease and PFAD biodiesel.

PFAD [Cheah et al., 2010], or 0.864 x 0.8. Finally, Table 7.2 shows the production coefficient for yellow grease from the literature.

7.3 Bioelectricity Production

Table 7.3 shows how much electricity producers can generate from one ton of waste biomass. The wastes include moisture that the palm oil mills must dry to low moisture levels to combust it. The palm oil mill can use direct combustion or integrated gasification combined cycle (IGCC). Direct combustion, the traditional technology, burns the biomass to generate heat and steam. Then the steam turns a turbine to generate electricity. Direct combustion converts approximately 27.7% of the heat energy into electricity [National Renewable Energy Laboratory, 2005], which engineers refer to as the Higher Heating Value (HHV) efficiency. The higher heating value includes the energy to vaporize water since the energy in steam helps generate electricity. On the other hand, the IGCC uses high temperatures to convert the waste biomass into gas comprised of hydrocarbons that, once ignited, turn a gas turbine. The residual heat then converts water into steam that turns a second turbine. In addition, the mills could use the natural gas combined cycle (NGCC) for methane because methane is already a gaseous hydrocarbon. The power industry has not widely adopted IGCC of NGCC since it is a new technology. However, both IGCC and NGCC convert 37% (HHV efficiency) of heat energy into electricity that exceeds the conversion efficiency of direct combustion [National Renewable Energy Laboratory, 2005]. Nevertheless, IGCC and INCC entail greater capital and operating costs. At last, Malaysia is a tropical country, and the power plants would not utilize the heat energy to heat buildings, such as the case in colder climates.

Equation 51 connects the heat energy in the feedstock to the amount of electricity the heat generates. The conversion, $1kcal = 0.001163kWh$, converts heat energy in kilocalories to electricity as kilowatt per hour (kWh), while the heat value is the total heat energy stored in the feedstock in dry tons. The formula includes an adjustment for moisture content (MC). MAPGEM, thus, includes both direct combustion and IGCC/NGCC in the renewable energy Leontief production function.

$$electricity\,(kWh/ton) = \frac{(1 - MC) \cdot heat\ value \cdot HHV\ efficiency \cdot 0.001163kWh}{1kcal} \tag{51}$$

Palm oil mills discharge water contaminated with high levels of organic material called palm oil mill effluent (POME) [Rupani et al., 2010]. POME kills vegetation on contact and consumes the oxygen in the water, thus killing the fish and marine life [Rupani et al., 2010]. The microorganisms in POME create and emit methane gas. Consequently, palm oil mills can cover the ponds and collect the methane to burn to generate bioelectricity. MAPGEM incorporates the burning of methane from POME but does not include other uses of POME. For instance, producers can dry POME and use residues as fertilizer [Rupani et al., 2010]. Microorganisms digest the POME that farmers and gardeners can use as soil amendments [Rupani et al., 2010]. Furthermore, vermicomposting allows earthworms to digest organic material in POME and create a high-quality soil [Rupani et al., 2010]. Finally, producers may transform POME into animal feed [Rupani et al., 2010].

MAPGEM allows producers to release the methane into the atmosphere that contributes to GHG emissions. The palm oil mills could cover the ponds to collect the methane. Then producers have a choice. The mills could burn the methane to generate electricity, which Table 7.3 shows, or they can flare the methane that transforms the methane into carbon dioxide. Carbon dioxide has a lower global warming potential than methane. For example, one metric ton of flared methane creates 2.25 tons of

Table 7.3: Waste Biomass Generated Electricity

Biomass	Feedstock Source	Moisture Content %	Heat Value kcal / dry ton	Direct Fired kWh/ton	IGCC kWh/ton
Banana residues	Banana	10.70	-	1,259.13	1,571.68
Coconut husk	Coconut	11.50	-	1,247.85	1,557.60
EFB	FFB	67.00	4,512,428.30	479.72	640.78
Methane	POME	nil	13,284,000.00	4,279.45	5,716.24
Oil palm fibers	FFB	37.09	4,555,449.33	923.23	1,233.20
Oil palm fronds	FFB	70.60	3,757,170.17	355.85	475.32
Oil palm shells	FFB	12.00	4,801,625.24	1,361.23	1,818.24
Oil palm trunks	Replanted	75.60	4,175,430.21	328.21	438.40
Pineapple waste	Pineapple	61.20	-	547.08	682.88
POME	FFB	93.00	4,060,707.45	91.57	122.32
Rice husk	Paddy	9.00	-	1,283.10	1,601.60
Rice straw	Paddy	11.00	-	1,254.90	1,566.40
Sugarcane bagasse	Sugarcane	15.00	3,633,353.00	994.92	1,328.95

Sources: Loh [2017] provides moisture level and heat value for EFB, oil palm fibers, oil palm fronds, oil palm shells, oil palm trunks, and POME. Ma et al. [1994] cites Chua [1993] for energy and moisture levels for palm oil products. Maung and McCarl [2013] provide information on rice straw. Soom et al. [2006] provide EFB. National Renewable Energy Laboratory [2005] calculates an average electricity yield of 1,410 kWh per ton bone dry weight (BDW) with direct fired and 1,760 kWh per ton bone dry weight for IGCC. The average electricity yield estimates the electricity generation for missing heat values. The production coefficients are entered into manufacture_energy_output(processing_energy, renewable_energy) in MAPGEM.

carbon dioxide, which Equation 52 shows. Methane has a global warming potential (GWP) of 25 while one metric ton of carbon dioxide equals one. In this case, the GWP drops from 25 to 2.25.

$$\begin{array}{llll} CH_4 + & 2O_2 \rightarrow & CO_2 + & 2H_2O \\ 16kg & 4kg & 36kg & 44kg \end{array} \quad (52)$$

7.4 Bioethanol Production

A palm oil mill could annex the capital to produce bioethanol from waste biomass because most of the waste biomass is available at the mill. The bioethanol substitutes for petrol. The hydrolysis reaction breaks down the cellulose and hemicellulose into glucose and xylose respectively. Then yeasts ferment the sugars into ethanol. Table 7.4 shows the ethanol yield in liters from one ton of feedstock given the moisture level.

The ethanol production coefficient entails two parts. First, refineries break down the cellulose into glucose and microorganisms would ferment the sugars into ethanol by the chemical reaction in 53 [Goh et al., 2010]. Second, the refinery breaks down hemicellulose into xylose so that microorganisms convert pentose sugars into ethanol via the chemical reaction 54 [Goh et al., 2010]. The theoretical ethanol yield equals one metric ton of glucose or xylose yield 0.5114 tons of ethanol, which is the ratio of 92.1369 kg and 180.1559 kg (or 230.3422 and 450.3897).

Table 7.4: Ethanol Chemical Yields from Waste Biomass

Feedstock	Moisture Content (% Wt)	Lignin (% DW)	Alpha Cellulose (% DW)	Hemicellulose (% DW)	Ethanol (liters/ton)
Banana residues	10.7	22.4	31.9	18.0	175.45
Coconut husk	11.5	32.8	44.2	12.1	201.16
EFB	67.0	17.6	54.4	28.0	107.45
Oil palm fibers	37.1	28.5	20.8	38.8	140.15
Oil palm fronds	70.6	14.8	62.3	24.2	101.54
Oil palm shells	12.0	50.7	20.8	22.7	146.48
Oil palm trunks	75.6	17.1	41.2	34.4	71.43
Paddy straw	11.0	6.0	35.0	21.0	195.74
Pineapple waste	61.2	4.7	19.4	22.4	61.91
Rice husk	9.0	17.6	35.1	20.9	200.21
Sugarcane bagasse	50.0	25.0	50.0	25.0	148.35

Sources: DW denotes dry weight. Moisture content comes from Bilba et al. [2007] for bananas. Coconut husks derived from Achaw and Afrane [2008]. Loh [2017] provides MC for EFB, oil palm fibers, oil palm fronds, oil palm shells, and oil palm trunks. Rice straw from Abdel-Mohdy et al. [2009]. Pineapple wastes from Idris and Suzana [2006]. Rice husks from Nordin et al. [2007]. Sugarcane bagasse from Akram et al. [2009]. The lignin, alpha-cellulose, and hemicellulose for bananas originate from Bilba et al. [2007]. Coconut husks from Khalil et al. [2007]. EFB from Sun and Tomkinson [2001]. Oil palm fibers from Law et al. [2007]. Oil palm shells from Yojiro and Ishizaki [1990]. Oil palm trunks from Kelly-Yong et al. [2007]. Rice straw from Wati et al. [2007]. Pineapple wastes from Ban-Koffi and Han [1990]. Rice husks from Nordin et al. [2007]. Sugarcane bagasse from Pandey et al. [2000]. The production coefficients are entered into manufacture_energy_output(processing_energy, renewable_energy) in MAPGEM.

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$$
$$180.1559\ kg \quad 92.1369\ kg \tag{53}$$

$$3C_5H_{10}O_5 \rightarrow 5C_2H_5OH + 5CO_2$$
$$450.3897\ kg \quad 230.3422\ kg \tag{54}$$

The chemical formulas in 53 - 54 depict the theoretical chemical yield. Converting cellulose into glucose has a yield of 76% while hemicellulose into xylose is 90% [Goh et al., 2010]. The fermentation conversion efficiency equals 75% for glucose and 50% for xylose. Subsequently, MAPGEM calculates the ethanol in liters that allow the comparison to petrol fuel. Ethanol has a density of 0.7895 kilograms per liter, which is divided by 1000 to convert to tons. Using Equation 55, we obtain the practical yield of ethanol from cellulose. We deduct the moisture content of the feedstock since water does not contribute to the reaction. Consequently, the potential chemical yield equals the theoretical chemical yield multiplied by the conversion efficiencies.

$$ethanol\,(liters/ton) = \frac{(1 - moisture\ content) \cdot cellulose \cdot 0.5114 \cdot 0.76 \cdot 0.85}{0.0007895} \tag{55}$$

Similarly, Equation 56 shows the ethanol yield from hemicellulose. The total ethanol in Table 7.4 sums the ethanol from both the pentose and hexose sugars. Thus, the ethanol yield equals the total liters of ethanol from one ton of feedstock with a given moisture level.

$$ethanol\,(liters/ton) = \frac{(1 - moisture\ content) \times hemicellulose \times 0.5114 \cdot 0.90 \cdot 0.60}{0.0007895} \tag{56}$$

The U.S. Department of Agriculture (National Resources Conservation Service) suggests that farmers should leave 30% residue cover to reduce soil erosion because soil erosion carries away nutrients and lowers organic matter that reduces soil fertility. The industry has found other uses for agricultural biomass. Farmers could utilize the waste biomass as natural fertilizers, water retention, soil fertility, forage for livestock, and ground cover to slow weed growth. Industries, for example, can utilize the fiber in biomass to make fiberboard [Basiron and Weng, 2004]. The furniture industry can use rubberwood from rubber trees to make furniture as plantation owners remove old trees [See and Krishnapillay, 2005]. At this time, MAPGEM does not include alternative uses of waste biomass except in the manufacturing of bioelectricity, butanol, and ethanol.

7.5 Biobutanol Production

We allow a palm oil mill to annex the capital to produce biobutanol from waste biomass. The butanol substitutes for petrol. The hydrolysis reaction breaks down the cellulose and hemicellulose into glucose and xylose, respectively, and similar to the last section on bioethanol. The microorganisms consume the glucose and xylose and produce acetone, butanol, and ethanol, otherwise known as ABE. Table 7.5 shows the ABE yield in liters from one ton of feedstock.

The ABE production coefficient entails two parts. First, refineries break down the cellulose into glucose and microorganisms would ferment the sugars into ABE by the chemical reactions in 57 - 59. The theoretical ABE chemical reaction occurs in ratios of 3:6:1 [Gapes, 2000, Pfromm et al., 2010, Ramey

Table 7.5: Butanol Chemical Yields from Waste Biomass

Type	Moisture Content (% W)	Lignin (% DW)	Alpha Cellulose (% DW)	Hemicellulose (% DW)	ABE Acetone liters/tonne	ABE Butanol liters/tonne	ABE Ethanol liters/tonne	Butanol Only liters/tonne
Banana residues	10.7	22.4	31.9	18.0	33.97	83.93	8.92	137.56
Coconut husk	11.5	32.8	44.2	12.1	38.68	95.56	10.16	157.73
EFB	67.0	17.6	54.4	28.0	20.79	51.35	5.46	84.25
Oil palm fibers	37.1	28.5	20.8	38.8	27.54	68.05	7.23	109.89
Oil palm fronds	70.6	14.8	62.3	24.2	19.59	48.39	5.14	79.62
Oil palm shells	12.0	50.7	20.8	22.7	28.59	70.64	7.51	114.85
Oil palm trunks	75.6	17.1	41.2	34.4	13.90	34.33	3.65	56.01
Paddy straw	11.0	6.0	35.0	21.0	37.93	93.70	9.96	153.48
Pineapple waste	61.2	4.7	19.4	22.4	12.09	29.88	3.18	48.54
Rice husk	9.0	17.6	35.1	20.9	38.79	95.83	10.19	156.97
Sugarcane bagasse	50.0	25.0	50.0	25.0	28.69	70.87	7.53	116.32

Sources: DW denotes dry weight. Moisture content comes from Bilba et al. [2007] for bananas. Coconut husks derived from Achaw and Afrane [2008]. Loh [2017] provides MC for EFB, oil palm fibers, oil palm fronds, oil palm shells, and oil palm trunks. Rice straw from Abdel-Mohdy et al. [2009]. Pineapple wastes from Idris and Suzana [2006]. Rice husks from Nordin et al. [2007]. Sugarcane bagasse from Akram et al. [2009]. The lignin, alpha-cellulose, and hemicellulose for bananas originate from Bilba et al. [2007]. Coconut husks from Khalil et al. [2007]. EFB from Sun and Tomkinson [2001]. Oil palm fibers from Law et al. [2007]. Oil palm shells from Yojiro and Ishizaki [1990]. Oil palm trunks from Kelly-Yong et al. [2007]. Rice straw from Wati et al. [2007]. Pineapple wastes from Ban-Koffi and Han [1990]. Rice husks from Nordin et al. [2007]. Sugarcane bagasse from Pandey et al. [2000]. The production coefficients are entered into manufacture_energy_output(processing_energy, renewable_energy) in MAPGEM.

and Yang, 2004]. Consequently, one metric ton of glucose yields 0.0967 of acetone, 0.2469 of butanol, and 0.0256 of ethanol. Second, the refinery breaks down hemicellulose into xylose so that microorganisms convert pentose sugars into ABE in the chemical reactions 60 - 62. Accordingly, one metric ton of xylose yields 0.1018 of acetone, 0.2599 of butanol, and 0.0269 of ethanol. At last, Table 7.5 shows the yield if newly engineered microorganisms can convert all the glucose and xylose into butanol and produce zero acetone and ethanol.

$$\begin{array}{c} Acetone : C_6H_{12}O_6 + H_2O \rightarrow CH_3COCH_3 + 4H_2 + 3CO_2 \\ 180.1559\ kg \qquad\qquad 58.0791\ kg \end{array} \tag{57}$$

$$\begin{array}{c} n - Butanol : C_6H_{12}O_6 \rightarrow C_4H_9OH + 2CO_2 + H_2O \\ 180.1559\ kg \quad 74.1216\ kg \end{array} \tag{58}$$

$$\begin{array}{c} Ethanol : C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \\ 180.1559\ kg \quad 92.1369\ kg \end{array} \tag{59}$$

$$\begin{array}{c} Acetone : 6C_5H_{10}O_5 + 5H_2O \rightarrow 5CH_3COCH_3 + 20H_2 + 15CO_2 \\ 900.7794\ kg \qquad\qquad 290.3957\ kg \end{array} \tag{60}$$

$$\begin{array}{c} n - Butanol : 6C_5H_{10}O_5 \rightarrow 5C_4H_9OH + 5H_2O + 10CO_2 \\ 900.7794\ kg \quad 370.6080\ kg \end{array} \tag{61}$$

$$\begin{array}{c} Ethanol : 3C_5H_{10}O_5 \rightarrow 5C_2H_5OH + 5CO_2 \\ 450.3897\ kg \quad 230.3422\ kg \end{array} \tag{62}$$

Equations 57 - 62 depict the theoretical chemical yields. We utilize the same glucose, xylose, and fermentation efficiencies as the bioethanol in the last section. We assume 76% of cellulose and 90% of hemicellulose yield glucose and xylose respectively while microorganisms can convert 85% of the glucose and 60% of the xylose into ABE. We convert the ABE into liters for comparison with the petrol.

7.6 Production Capacity Constraint

We can impose a production capacity constraint on the model. Palm oil mills are not likely to instantaneously boost their production capacity in a short-time frame. Accordingly, MAPGEM allows researchers to impose a production capacity constraint. Table 7.6 shows the production constraint for each renewable energy by the state. The production capacity is portioned over the states by palm oil hectares. MAPGEM gives users the ability to turn on or off the production constraint and specify how quickly production capacity grows over time. We do not impose a constraint on acetone and methane. Acetone is a byproduct of the butanol reaction while the capital may not be extended to cover the POME and collect and flare the methane.

Table 7.6: Production Capacity of Renewable Energy (units)

State	Biodiesel liters	Bioelectricity kWh	Butanol liters	Ethanol liters	Acetone	Flare Methane
Johore	377,534.5	7,703,262.7	377,534.5	377,534.5		
Kedah	44,535.4	908,705.9	44,535.4	44,535.4		
Kelantan	77,577.6	1,582,902.7	77,577.6	77,577.6		
Melaka	27,873.2	568,727.6	27,873.2	27,873.2		
N. Sembilan	90,731.4	1,851,294.1	90,731.4	90,731.4		
Pahang	370,212.4	7,553,860.1	370,212.4	370,212.4		
Penang	7,374.8	150,475.4	7,374.8	7,374.8		
Perak	203,327.1	4,148,712.7	203,327.1	203,327.1		
Perlis	150.1	3,062.2	150.1	150.1		
Selangor	70,105.8	1,430,448.4	70,105.8	70,105.8		
Terengganu	88,100.4	1,797,611.6	88,100.4	88,100.4		
Sabah	788,278.7	16,084,138.5	788,278.7	788,278.7		
Sarawak	734,748.8	14,991,908.2	734,748.8	734,748.8		
Total	2,880,550	58,775,110	2,880,550	2,880,550		

References: The production_capacity(state, renewable_energy) in MAPGEM holds the maximum production capacity for renewable energy.

7.7 Operating and Capital Costs

The palm oil mills should lead in bioenergy production since the palm plantations supply about 97% of the waste biomass and byproducts. Table 7.7 shows the itemized costs for crushing FFB, biodiesel, butanol, and ethanol. Palm oil mills could have economies of scale, whereas the mills reduce their per-unit costs for larger processing capacities. However, MAPGEM, at this time, holds per-unit costs constant. The budget costs in Table 7.7 process 336,659.04 metric tons of FFB for a palm oil mill in Sabah [Man and Baharum, 2011] while biodiesel production is based on a 100,000 metric ton capacity for palm oil [Lopez and Laan, 2008]. Furthermore, the biodiesel cost in MAPGEM is set to RM690.4644 to calibrate production to 2015 statistics. Biodiesel production also creates glycerin as a byproduct that producers sell to the chemical industry. Thus, glycerin becomes a credit in the cost budget. Furthermore, the mills pay an additional RM50 per ton for PFAD for acid treatment upgrades and RM150 per metric ton to collect yellow grease. Then the mills could convert both PFAD and yellow grease into biodiesel. In addition, the operating and capital costs of ethanol is based on a 304 million liter capacity with a capital of 381 million USD [Tao et al., 2014]. The capital is amortized at 8% over 10 years [Tao et al., 2014]. Finally, the ABE fermentation is based on a capacity of 37.8541 million liters of butanol per year. The capital lasts 20 years and amortized at 15%. The capital costs USD0.4121 per liter with operating costs of USD0.2642 per liter [Ramey and Yang, 2004]. Butanol produces acetone and ethanol as byproducts, which the mills can sell acetone for RM1.9082 per liter [Milner, 2016] and ethanol for RM2.8168 per liter [Ellis, 2015].

Table 7.8 shows the average bioelectricity operating and capital costs for direct combustion of electricity. Direct combustion is the mature technology to generate electricity with an average combustion costs of RM0.3101 per kWh while the IGCC averages 0.3944 per kWh. Although gasification entails greater capital costs, the technology converts more heat energy into electricity. Finally, landfill gas comprises the last operating and capital costs that we use as a proxy for costs of collecting methane from POME. Landfill gas would utilize identical storage and generator, but the collection system would differ from POME. Landfill gas costs on average RM0.5097 kWh for direct combustion. Then we raised the cost of NGCC by 30% for RM 0.6625 per kWh.

Table 7.7: Operating and Capital Costs

Item	Crushing FFB	Biodiesel	Ethanol	Butanol
Prices based on	Fresh Fruit Bunches	Crude Palm Oil	Ethanol	Butanol
Year	2009	2007	2012	2004
Price units	RM/ton	RM/ton	USD/liter	USD/liter
Chemicals & enzymes		100.00	0.0972	
Capital and fixed costs	9.8	140.00	0.1059	0.4121
Dispatch	8.85			
Effluent treatment	0.29			
Glycerine credit		70.00		
Net Electricity			-0.0423	
Labor		25.00		
Laboratory	0.23			
Maintenance	12.14			
Methanol		161.00		
Operating costs				0.2642
Overhead	3.84	120.00		
Storage	0.53			
Taxes	0.52		0.0328	
Utilities	0.04	32.00		
Waste Disposal			0.0066	
Yield loss		142.00		
Return on Investment		142.00	0.1506	
—- Total	36.24	650.00	$0.3508 / liter	$0.6763 / liter
Exchange Rate (RM / $)			3.0862	3.8000
Producer Price Index	0.9080	0.9002	1.0939	0.7544
Real costs in 2015	39.91 RM/ton	722.06 RM/ton	0.9897 RM/liter	3.4065 RM/liter

Source: Palm oil mill data came from Man and Baharum [2011]. Biodiesel from Lopez and Laan [2008]. Ethanol from Tao et al. [2014]. Exchange rate from Board of Governors of the Federal Reserve System [2017]. Producer price index from Department of Statistics Malaysia [2014a]. The ethanol and butanol costs in RM per renewable energy are entered in energy_costs(renewable_energy) while the biodiesel and bioelectricity costs depend on the feedstock. Thus, the manufacture_energy_cost(processing_energy) holds the biodiesel and bioelectricity costs in RM per feedstock input.

Table 7.8: Bioelectricity Costs

Combustion	Year	Type	$ Cost $ per kWh	Exchange Rate (RM / $)	RM Cost RM per kWh	Producers Price Index 2015	Real Price RM per kWh
Source 1	2000	Ag residue	0.0503	3.8	0.1911	0.6928	0.2758
Source 2	2000	Forest biomass	0.04564	3.8	0.1794	0.6928	0.2589
Source 3	2011	Rice Straw	0.0676 - 0.0899	3.0564	0.2066 - 0.2748	1.0988	0.1880 - 0.2501
Source 4	2010	Biomass	0.06 - 0.21	3.2175	0.1931 - 0.6757	0.9785	0.1973 - 0.6905
IGCC					Rm per kWh		
Source 5	2010	Corn stover	0.1351	3.2175	0.4347	0.9785	0.4443
Source 6	2011	Thinned Wood	0.2	3.0564	0.6113	1.0988	0.5563
Source 7	2012	Forest residue	0.0604 - 0.0623	3.0862	0.1864 - 0.1923	1.0939	0.1704 - 0.1758
Source 8	2010	Biomass	0.07 - 0 24	3.2175	0.2252 - 0.7722	0.9785	0.2301 - 0.7892
Landfill Gas							
Source 9	2010	Biomass	0.07 - 0 24	3.2175	0.2252 - 0.7722	0.9785	0.2301 - 0.7892

Sources: Sources 1 and 2 came from Kumar et al. [2003]. Source 3 from Delivand et al. [2011]. Sources 4, 8, and 9 from International Renewable Energy Agency [2012]. Source 5 from Kumar et al. [2010]. Source 6 from Yagi and Nakata [2011]. Source 7 from Upadhyay et al. [2012]. Exchange rate came from Board of Governors of the Federal Reserve System [2017]. Producer price index came from Department of Statistics Malaysia [2014a].

7.8 Transportation Costs

MAPGEM include the cost to deliver the renewable energy to the market. The palm oil mills would ship the biodiesel, butanol, and ethanol to a refinery to blend with transportation fuel and then to retail stations. Table 7.9 shows the average distance to transport renewable energy from a state's center to a large city on the peninsula, such as Kaula Lumpur, Seberang Perai, Kajang, and Klang. The refineries located in Sarawak can ship liquid fuels to Kuching while refineries in Sabah would ship to Kota Kinabalu. We could not find the transportation cost in the literature. Thus, we use a cost of RM0.001 per liter-km to ship liquid fuels to the markets.

The mills would install transmission lines to provide bioelectricity to connect the mills to the national grid. Table 7.9 shows the infrastructure average cost in RM per kilometer amortize over 10 years at the interest rate of 8%. The palm oil mills, unfortunately, may not invest in the capital to generate electricity from biomass [Umar et al., 2013]. 36.9% of mills are located 10km or less to the nearest transmission line while 23.8% of mills are located over 40 km from the nearest grid [Umar et al., 2013]. We calculate an average weighted distance of 23 km for transmission lines. We derive the transmission line costs from Kumar et al. [2003]. A transmission line spans 300 km with a capacity of 900MW and capital costs of $97 million and operating costs of $408,000. We assume the line operates at 85% capacity during the year, which means the line is used 7,451.1 hours out of 8,766 hours in one year. If we amortize the capital costs for 10 years at 8% interest, the line costs 2.1557 USD per MW-h for capital cost and 0.0608 USD per MWh for operating cost. Converting to RM and adjust using the producers' price index, the costs for Malaysia is RM12.1575 per MWh or RM4.0525E-05 per KWH-km. At last, Table 7.9 includes flaring methane with zero costs.

The model includes several hauling costs of waste biomass. The palm oil mills pay RM264.26 per metric ton (or 67.69 USD [Maung and McCarl, 2013]) to haul banana wastes, coconut husks, pineapple waste, rice husk, and rice straw from the farmers. Furthermore, the mills pay RM100 per ton for the oil palm trunks when the plantation owners cut down the mature oil palms and plant with new ones. Finally, the palm oil mills avoid hauling costs for empty fruit baskets, palm fiber, and palm shells since the biomass is created on site. Finally, the mills would pay minimal costs for palm fronds because the plantation owners would always be pruning and cultivating their trees.

7.9 GAMS Code and Mathematics

The Leontief renewable energy production functions resemble the crop and plantation Leontief production functions. The Leontief production functions require two equations - the input and output. Equation 63 shows the output of renewable energy, where the decision variable, energy inputs (EI) allocates a biomass or byproduct to a process energy (pe) that, in turn, makes renewable energy. The amount of bioenergy (B) supplied at each time (t), state (s), and type of renewable energy (re) equals the production coefficients in the manufacture energy output (MEO) times the feedstock allocated to each process.

$$\sum_{pe} MEO_{re,pe} \cdot EI_{pe,s,t} = B_{t,s,re} \tag{63}$$

The GAMS code for Equation 63

```
balance_energy_outputs(year, state, renewable_energy)..

sum(processing_energy, manufacture_energy_output(processing_energy, renewable_energy)
* energy_inputs(year, state, processing_energy) ) =e= bioenergy(year, state, renewable_energy);
```

Table 7.9: Distance to Market (km)

State	Source	Destination	Distance	Bioelectricity
Johore	Kluang	Kajang, Klang	251.00	23.035
Kedah	Sik	Seberang Perai	90.40	23.035
Kelantan	Dabong	Seberang Perai	286.00	23.035
Melaka	Bemban	Kajang, Klang	129.00	23.035
N. Sembilan	Kuala Pilah	Kajang, Klang	84.80	23.035
Pahang	Bandar Tun Razak	Kaula Lumpur	168.00	23.035
Penang	Bukit Mertajam	Seberang Perai	7.30	23.035
Perak	Kuala Kangsar	Seberang Perai	111.00	23.035
Perlis	Kuala Perlis	Seberang Perai	157.00	23.035
Selangor	Rawang	Kaula Lumpur	32.80	23.035
Terengganu	Kuala Dungun	Kaula Lumpur	365.00	23.035
Sabah	Beluran	Kota Kinabalu	204.00	23.035
Sarawak	Bintulu	Kuching	618.00	23.035

References: The market_distance(state, renewable_energy) in MAPGEM holds the distance to ship renewable energy to the market while the transport_charge(renewable_energy) has the rate charge.

Equation 64 is the input for the Leontief production functions. The decision variable, transfer (T), transports commodities and waste biomass from the domestic production to the renewable Leontief production functions. The transfer includes commodity (i) for each time (t) and state (s). Then the decision variable, energy input (EI) allocates a commodity to a process energy (pe). The matrix, manufacture energy input (MEI) comprises of zeros and ones that account for each metric ton of biomass used. Usually, the input production equation uses a less than or equal sign, but the equal sign forces the utilization of biomass. Otherwise, a process would take biomass and produce zero renewable energy for a carbon tax.

$$\sum_{pe} MEI_{i,pe} \cdot EI_{pe,s,t} = T_{t,s,i} \tag{64}$$

The GAMS code for Equation 64.

```
balance_energy_inputs(year, state, commodities)..

sum(processing_energy, manufacture_energy_input(processing_energy, commodities)
* energy_inputs(year, state, processing_energy) ) =e= transfer(year, state, commodities) ;
```

Imposing a production capacity (PC) constraint is straightforward. The quantity of bioenergy (B) manufactured at a time (t), state (s), and type of bioenergy must lie below production capacity in Equation 65. A researcher can allow the capacity to grow over time by specifying the scalar for capacity growth (CG) in annual percent. MAPGEM starts year 2015 ($t = 1$) with five year increments.

$$B_{re,s,t} \leq PC_{re,s} \cdot \left(1 + \frac{CG}{100}\right)^{5t-5} \tag{65}$$

The GAMS code is below. The code uses an off-on switch called on_off_capacity that determines whether to impose production capacity.

```
production_constraint(year, state, renewable_energy)$on_off_capacity..
```

```
bioenergy(year, state, renewable_energy) =l= production_capacity(state, renewable_energy)
* (1 + capacity_growth / 100)**(5*ord(year) - 5) ;
```

It does not make sense to produce more bioenergy (B) than what a country needs. We impose an upper limit (UL) of the future energy consumption in Equation 66. We estimate the future energy consumption by multiplying the energy usage per capita by the Malaysian population forecast. We discovered this upper limit by accident. Malaysia produces more than enough palm oil to completely offset its diesel fuel consumption by palm biodiesel. Producers do not have an incentive to produce more biodiesel than what the transportation sector will impose.

$$\sum_{s} B_{re,s,t} \leq UL_{re,t} \tag{66}$$

The GAMS code is below to impose an upper limit on renewable energy.

```
renewable_constraint(year, renewable_energy)..

sum(state, bioenergy(year, state, renewable_energy) ) =l=
upper_limit(year, renewable_energy) ;
```

The government mandate shares similarities with the production capacity constraint. Instead of ensuring a mill must produce at or less than its capacity, the mandate requires a mill to supply a minimum level of bioenergy (B). In Equation 67, the upper limit (UL) matrix holds the fossil energy forecast. The upper limit connects the renewable energy (re) to its respective fossil fuel. For example, biodiesel goes with the diesel fuel forecast while both ethanol and butanol are associated with petrol. Finally, bioelectricity connects with the electricity forecast. Furthermore, the minimum bioenergy requires mills to produce a percentage of the minimum fuel mandate times the forecasted energy consumed at each time period (t). The mandate is specified as a percent of its respective fossil energy usage. MAPGEM calculates the forecasted energy usage by multiplying the population forecast times the 2015 energy per capita usage. Equation 67 shows the mandate for all forms of renewable energy. Finally, the $\phi()$ is an indicator function that turns on or off the minimum fuel requirement.

$$\sum_{s} B_{re,s,t} \geq \phi re \cdot min\ fuel\ mandate \cdot \frac{UL_{re,t}}{100} \tag{67}$$

The GAMS code adds two conditions to the minimum fuel mandate. The user can turn on the constraint by placing a one in the turn_on_mandate for biodiesel while zero turns it off. Then the constraint, $ord(year) > 1$ imposes the constraint for year 2020 and later since MAPGEM begins at year 2015 ($t = 1$). The command, ord, returns an integer to indicate a year's position in the year vector.

```
biofuel_mandate(year, renewable_energy)$(ord(year) > 1) ..

sum(state, bioenergy(year, state, renewable_energy) ) =g=
turn_on_mandate(renewable_energy) * min_fuel_mandate(renewable_energy)
* upper_limit(year, renewable_energy) / 100 ;
```

8 Greenhouse Gas Emissions

MAPGEM contains the significant emissions and sinks of greenhouse gases of renewable energy, land change, growing trees, resources, commodities, and waste biomass. We coded MAPGEM to associate emissions or sinks with a decision variable, so MAPGEM can influence the variable if the government imposes a carbon tax.

MAPGEM allows researchers to evaluate the economic impact of carbon taxes assessed on greenhouse gas emissions and sinks. Carbon taxes are assessed in RM per metric ton of carbon equivalent. Consequently, producers planting trees or supplying renewable energy would receive credits or subsidies since the activities sequester carbon. The 100-year global warming potential (GWP) converts methane and nitrous oxide into carbon dioxide equivalents. Carbon dioxide has a GWP of 1.0, methane 25.0, and nitrous oxide 298.0 [Intergovernmental Panel on Climate Change, 2007][1]. Then the model connects a carbon tax to carbon dioxide equivalent emissions by multiplying by 12 and dividing by 44, which are the masses of carbon and carbon dioxide respectively.

MAPGEM maintains the carbon tax at the same level for all time periods. Some researchers allow carbon taxes to increase over time while the tax penalizes producers emitting GHG. The forestry sector, on the other hand, would receive more subsidies over time [Sathaye et al., 2006] as growing trees serve as a sink for carbon dioxide. However, we maintain a constant carbon tax since the government would have to pay higher subsidies to expand forests and mitigate greenhouse gas emissions. Also, the literature is not clear about how much carbon taxes should increase over time.

8.1 Greenhouse Gas Emissions, Sequestration, and Sinks

Table 8.1 shows the life-cycle reductions of greenhouse gases from renewable energy and includes biodiesel, butanol, ethanol, bioelectricity, and flaring methane. For example, one liter of biodiesel that substitutes for diesel fuel lowers carbon dioxide by 0.0003472 tons. Furthermore, biodiesel influences methane and nitrous oxide emissions. The carbon dioxide equivalent emissions use the global warming potential to convert all GHG into their carbon dioxide equivalents (CO2-eq). On the other hand, methane from POME is a complex product because producers can release methane into the air, flare the methane to reduce its global warming potential, or combust the methane to generate electricity. From the last chapter, one metric ton of methane with a GWP of 25 creates 2.25 tons of carbon dioxide with a GWP of 2.25. (Then we assume methane comprises of 30% carbon dioxide which amounts to 0.4286 if methane is set at one). If producers burn methane to generate electricity, we assume the life-cycle greenhouse gas emissions are identical to biomass reducing coal usage. In Peninsular Malaysia in 2012, 53.0% of electricity came from coal, 42.5% from natural gas, 2.5% from oil, and 2.1% from diesel [Green Tech Malaysia, 2013].

The Table 8.2 shows the mills emissions for GHG. The collection of yellow grease omits the emissions for trucks to collect yellow grease from restaurants but includes the GHG emissions from biodiesel conversion. Finally, we could not find the emissions for cocoa, coconut, and latex processing in the literature.

Table 8.3 shows the GHG emissions to transport the renewable energy to the markets. The mills ship biodiesel, butanol, and ethanol to a petroleum companies' refinery, where it blends biodiesel with diesel, and ethanol and butanol with petrol. Then the refinery ships the fuel mixes to the petrol stations. The

[1]The matrix, gwp(ghg_gases), in MAPGEM contains the GWP of gases

Table 8.1: Bioenergy GHG Mititgation (tons per unit)

Biofuel	Unit	Carbon Dioxide	Methane	Nitrous Oxide	CO2-eq
Acetone	liter				
Biodiesel	liter	-0.0003472	-1.9813E-07	-6.8685E-08	-0.0003726
Bioelectricity	kWh	-0.000741	0.0	0.0	-0.000741
Butanol	liter	-0.0019323	-1.4812E-07	-8.0795E-08	-0.0019601
Ethanol	liter	-0.0022772	-7.2924E-08	-3.0662E-08	-0.0022882
Flare methane	tons	2.788500	0.0	0.0	

Sources: Bioelectricity came from Green Tech Malaysia [2013]. Biodiesel from The Climate Registry [2008]. The ethanol and petrol emissions are based on a flexible fuel vehicle using E85 and calculated from the average mileage of a Myvi Malaysian car from Ramdan and Lim [2015] and emissions from Zhai et al. [2009]. The butanol emissions are derived from Ramey and Yang [2004]. The table, ghg_recycle(renewable_energy, ghg_gases), contains life-cycle emissions for renewable energy in MAPGEM.

Table 8.2: GHG Mill Emissions (tons per unit)

Plantation Processing	Carbon Dioxide	Methane	Nitrous Oxide	CO2-e
Cocoa Coconuts	0.0	0.0	0.0	0.0
Crush FFB	0.006619	0.0	0.0	0.006619
Biodiesel	0.083122			0.083122
Collect yellow grease	0.083122	0.0	0.0	0.083122
Latex	0.0	0.0	0.0	

Sources: Pehnelt and Vietze [2013] supplies greenhouse gas emissions for crushing FFB, making biodiesel, and collecting grease.

emissions reflect a diesel truck transporting the liquid fuel. The truck has a limited capacity, so the table reflect the GHG per liter-kilometer. The average distance starts at a state's center, the mills' location, and ships the renewable energy to the nearest largest city on the peninsula, such as Kaula Lumpur, Seberang Perai, Kajang, and Klang. The refineries in the center of Sarawak ship liquid fuels to Kuching while mills in Sabah transport fuels to Kota Kinabalu. On the other hand, the transmission lines connect the palm oil mills to the national grid. Although transmission lines emit little GHG during operations, the installation of the infrastructure would emit GHG. Unfortunately, the research literature contains little information GHG emissions.

Table 8.4 shows the GHG emissions from changing land use. The emissions originate from clearing the land and developing the infrastructure to establish an oil palm plantation. The GHG emissions are based on several assumptions. First, producers do not burn the trees since Malaysia has laws to prevent burning. Second, cocoa, coconut, and rubber plantations are cut down at maturity. Nevertheless, GHG emissions from land conversion are variable [Melling and Henson, 2011]. Changing land use may also raise methane and nitrous oxide emissions, but emissions depend on a variety of factors [Melling and Henson, 2011]. Finally, landowners converting virgin rainforests into oil palm plantations may increase carbon dioxide emissions as decomposition and water runoff remove the stored carbon from soils especially for peat soils [Melling and Henson, 2011]. At this time, we do not have enough information to include these carbon emissions.

Table 8.5 accounts for the carbon storage of the trees. As the trees grow and develop deep roots, the tree's structures store carbon as the building blocks of a tree's structures. Leaves falling to the ground, furthermore, add carbon to the soil over time. For example, one hectare of oil palms can absorb approximately 197 tons of carbon dioxide during their productive life [Rodrigues et al., 2014]. MAPGEM includes carbon storage in trees, while a carbon tax becomes a subsidy to plantation owners to allow trees to grow and store carbon. Carbon stored in trees depend on many factors such as growth rate, tree density, soil nutrients, rainfall, and tree age. For example, Henson [2009] estimates 30-year oil palm trees store 32.78 tons of carbon per hectare in roots, shoot, ground cover, and male inflorescence piles. We assume one hectare of oil palm trees removes 1.09266 metric tons of carbon from the atmosphere or recycles 4.0064 tons of carbon dioxide per year. (We multiply by 44 and divide by 12, which are the masses of carbon dioxide and carbon respectively) Fronds are excluded since palm oil mills can utilize fronds to generate bioelectricity or ferment into ethanol or butanol. In addition, farmers harvest the kenaf and paddy at the end of the growing season, so these crops store little carbon except in their products biomass. Similarly, the banana tree, pepper, and pineapple store little carbon except in their products and biomass. Table 8.5, moreover, includes the methane emissions from rice cultivation.

MAPGEM include the following resources: labor, nitrogen, phosphorus, and potash. To maintain simple code, MAPGEM allows each resource to emit or sink greenhouse gases. Currently, no government

Table 8.3: GHG Emissions from Transportation (metric tons per liter-kilometer)

Biofuel	Unit	Carbon Dioxide	Methane	Nitrous Oxide	CO2-e
Biodiesel	liter	7.7452e-08	8.7500e-12	0.0	7.7671e-08
Bioelectricity	kWh	0.0	0.0	0.0	0.0
Butanol	liter	7.1698e-08	8.1000e-12	0.0	7.1901e-08
Ethanol	liter	6.9879e-08	7.8945e-12	0.0	7.0077e-08
Flare methane	tons	0.0	0.0	0.0	0.0

Sources: Greenhouse gas emissions are derived from Pehnelt and Vietze [2013], who provide the emissions in grams of gas emitted per metric ton-kilometer.

Table 8.4: GHG Emissions of Changing Land Use (tons per hectare)

Plantation type	Carbon dioxide	Methane	Nitrous Oxide
Cocoa trees	0.4000		
Coconut trees	0.4000		
Forest	0.4800		
Oil palm 0y			
Oil palm 5y			
Oil palm 10y			
Rubber trees	0.4000		

Source: The carbon storage for forest and rubber originate from Turner and Gillbanks [2003]. We assume land clearing for cocoa and coconut plantations are similar to rubber. The table, change_land_ghg(type, ghg_gases), holds the GHG emissions of changing land use in MAPGEM.

Table 8.5: Carbon storage from crops and trees (tons per hectare)

Crops	Economic Life	Carbon dioxide	Methane	Nitrous Oxide
banana tree		0.00		
durian tree	40	-12.19167		
kenaf		0.00		
mango tree	40	-11.10083		
papaya tree	4			
pepper		0.00		
paddy		0.00	0.178917	
pineapple plant		0.00		
rambutan tree	40	-10.81667		
Plantation type				
Cocoa trees	25	-3.30000		
Coconut trees	20	-4.95000		
Forest		-9.33610		
Oil palm trees, 0y		0.00000		
Oil palm trees, 5y		-4.00644		
Oil palm trees, mature	30	-4.00644		
Rubber trees	15	-15.2900		

Source: Cocoa came from Selecky et al. [2017]. Coconut came from Selvaraj et al. [2016]. Durian, mango, and rambutan came from Kirsfianti et al. [2002]. Oil palm came from Henson [2009]. Rice emissions from Food and Agriculture Organization of the United Nations [2014a] while forest sequestration from Food and Agriculture Organization of the United Nations [2015]. Rubber from Maggiotto et al. [2014]. Carbon tree storage for plantations is in table, trees_ghg(type, ghg_gases) in MAPGEM while crop_carbon_storage(crops, ghg_gases) contains GHG for crops.

imposes a carbon tax on laborers, but MAPGEM allows such a possibility. On the other hand, Table 8.6 shows the GHG emissions for fertilizers by components. Pehnelt and Vietze [2013] estimates the life-cycle emissions for nitrogen, phosphorus, and potash for all crops and trees originates from the fertilizer manufacturing. The table also adds the nitrous oxide emissions from applying nitrogen to a crop or tree. The nitrous oxide emissions are variable and depend on the crop or tree as well as the bacteria in the soil that consumes the nitrogen and converts it to nitrous oxide. The nitrous oxide excludes the nitrous oxide emissions from manufacturing since they comprise a small component of the emissions. MAPGEM, at this time, does not allow different technologies to apply fertilizer to mitigate GHG emissions.

Table 8.7 shows the GHG emissions from agricultural commodities and waste biomass. The table has three caveats. First, the waste biomass has zero carbon emissions because the model assumes the carbon is released into the atmosphere. Thus, the net impact on GHG emissions would be zero, and the model excludes the carbon storage of waste biomass. In addition, we assume plantation owners and farmers use the waste biomass as mulch. The mulch degrades over time emitting 1.25% of their dry weight as nitrous oxide. The nitrous oxide takes a large penalty from GWP and encourages manufacturers to convert waste biomass into renewable energy. Second, the researchers estimate the percent carbon composition for banana, cocoa bean, coconut, durian, mango, papaya, pepper, pineapple, rambutan, and rice from the moisture, protein, sugar, carbohydrate, and fat content. (A similar procedure helps estimate the carbon content of banana residue, coconut husk, kenaf, latex, palm frond, pineapple waste, rice husk, and rice straw). Consequently, mango and papaya have low carbon content because the fruits comprise mostly of water. Finally, MAPGEM treats methane as a pure commodity. However, methane from POME contains 60 to 70% methane, 30 to 40 carbon dioxide, and traces of hydrogen sulfide [Hassan et al., 2011, Ma et al., 1994]. In Table 8.7, we treat methane as containing 35% carbon dioxide and 65% methane. Finally, some researchers omit carbon dioxide emissions from natural sources, but we include all emissions and sinks.

8.2 GAMS Code and Mathematics

Although the GAMS code looks complicated, the code is straightforward. The code tabulates the cumulative GHG emissions from every source and sink in the model. MAPGEM uses the aggregate emissions to calculate the economic consequences of a carbon tax or tabulate emissions. Consequently, every table in this chapter is represented below times its respective decision variable. Some variables require the multiplication of three factors. For example, fertilizer usage is calculated from the hectares of land in plantations times the matrix plantation resources. Then the resource usage is multiplied by the table on resource GHG emissions. Distance to the market is a product of three terms also. The code, finally, maintains cumulative GHG emissions of carbon dioxide, methane, and nitrous oxide. The GAMS code below aggregates all GHG in the model.

```
   aggregate_ghg(year, state, ghg_gases)..

   greenhouse_gases(year, state, ghg_gases) =e=
   sum(renewable_energy, bioenergy(year, state, renewable_energy) * ghg_recycle(renewable_energy,
ghg_gases))
   + sum(processing_plantations, mills_ghg(processing_plantations, ghg_gases)
   * plantation_inputs(year, state, processing_plantations) )
   + sum(renewable_energy, bioenergy(year, state, renewable_energy) * market_distance(state, renewable_energy)
   * transport_ghg(renewable_energy, ghg_gases) )
   + sum(type, convert(year, state, type) * change_land_ghg(type, ghg_gases) )
   + sum((crops, resources), cropland(year, state, crops) * crop_resources(state, crops, resources)
   * crops_ghg(crops, resources, ghg_gases) )
   + sum((type, resources), hectares(year, state, type) * plantation_resources(state, type, resources)
   * plantation_ghg(type, resources, ghg_gases) )
```

Table 8.6: Fertilizer GHG emissions (GHG tons per ton fertilizer)

Nitrogen-Crops	Carbon dioxide	Methane	Nitrous Oxide
Banana	2.8270	0.0087	0.0210
Durian	2.8270	0.0087	0.1704
Kenaf	2.8270	0.0087	0.0133
Mango	2.8270	0.0087	0.1704
Papaya	2.8270	0.0087	0.1704
Pepper	2.8270	0.0087	0.0133
Pineapple	2.8270	0.0087	0.0133
Paddy	2.8270	0.0087	0.0075
Rambutan	2.8270	0.0087	0.1704
Nitrogen-Plantations			
Cocoa trees	2.8270	0.0087	0.1704
Coconut trees	2.8270	0.0087	0.1704
Forest	0.0	0.0	0.0
Oil palm trees, 0y	2.8270	0.0087	0.2053
Oil palm trees, 5y	2.8270	0.0087	0.1441
Oil palm trees, mature	2.8270	0.0087	0.1619
Rubber trees	2.8270	0.0087	0.1704
All crops and trees			
Phosphorus	0.9649	0.0013	0.0001
Potash	0.5363	0.0016	0.0000

Applying synthetic nitrogen fertilizer to crops comes from Food and Agriculture Organization of the United Nations [2014b]. Banana nitrogen comes from Veldkamp and Keller [1997]. Kusin et al. [2015] provides the nitrous fertilizer emissions for oil palm plantations. Paddy from Hua et al. [1997]. At last, Pehnelt and Vietze [2013] provides life-cycle emissions for nitrogen, phosphorus and potash. Plantation fertilizer emissions are in table, plantation_ghg(type, resources, ghg_gases) in MAPGEM while crops are in crops_ghg(crops, resources, ghg_gases).

Table 8.7: GHG Emissions and Storage

Products	Moisture (%)	Carbon (%)	Carbon dioxide (tons)	Methane (tons)	Nitrogen (%)	Nitrous Oxide (tons)
banana		8.2839	-0.3037			
banana residue		34.4395	-0.0000			0.0112
cocoa bean		42.5133	-1.5588			
coconut		38.2714	-1.4033			
coconut husk		43.6520	-0.0000			0.0111
durian		16.3162	-0.5983			
efb	67.00	48.7150	-0.0000		0.2490	0.0044
kenaf		41.5680	-1.5242			
latex		75.0000	-2.7500			
mango		7.0954	-0.2602			
methane			0.5385	1.0000		0.0000
palm biodiesel		75.0000	-2.7500			
palm fiber	37.09	46.3960	-0.0000		0.3910	0.0077
palm frond	70.60	48.4310	-0.0000		12.4020	0.1146
palm kernel cake	0.28	45.7370	-1.6723		2.4260	-0.0760
palm kernel oil	0.07	72.0000	-2.6400			
palm oil	0.07	76.8910	-2.8174		0.0000	0.0000
palm shell	12.00	57.9090	-1.8685		0.0430	0.0012
palm trunk	75.60	41.659	-0.3681		0.0430	0.0012
papaya		4.4305	-0.1625			
pepper		34.8481	-1.2778			
pfad			-1.0000			
pineapple		5.0855	-0.1865			
pineapple waste		20.0383	-0.7347			0.0049
pome	93.00	50.0130	-0.1284		1.9870	0.0044
rambutan		7.2442	-0.2656			
rice		39.3782	-1.4439			
rice husk		33.9869	-0.0000			0.0114
rice straw		26.8302	-0.0000			0.0111
yellow grease		75.0000	-2.7500			

Source: Composition of banana, cocoa bean, durian, mango, papaya, pepper, pineapple, and rice came from Agricultural Research Service [2015]. Banana residue from Bilba et al. [2007]. Coconut composition from Duke [1983]. Coconut husk from Khalil et al. [2007]. Kenaf from Jonoobi et al. [2009]. The carbon, nitrogen, and moisture content for EFB, palm fiber, palm frond, palm kernel meal, palm oil, palm shell, palm trunk, and POME came from Loh [2017]. Palm kernel oil from Ross et al. [1992]. Pineapple waste from Ban-Koffi and Han [1990]. Rambutan composition from Zee [1998]. Rice husk form Nordin et al. [2007]. Rice straw from Wati et al. [2007]. Latex is derived from isoprenoid, which is a polymer of $(C_{15}H_{24})_n$ dried to 15%. We assume yellow grease contains the same carbon content as palm oil. Nitrous oxide emissions from waste biomass equal 1.25% for dry weight [Smith et al., 1999]. The table, _ghg(commodities, ghg_gases), holds the GHG emissions of the products and waste biomass in MAPGEM.

```
   + sum(commodities, production(year, state, commodities) * products_ghg(commodities, ghg_gases)
)
   + sum(type, hectares(year, state, type) * trees_ghg(type, ghg_gases) )
   + sum(crops, crop_carbon_storage(crops, ghg_gases) * cropland(year, state, crops) ) ;
```

MAPGEM uses the GAMS code below to calculate the impact of a carbon tax on GHG emissions of renewable energy. The code excludes other GHG sources in the model.

```
renewable_ghg(year, state, ghg_gases)..

greenhouse_gases_re(year, state, ghg_gases) =e= sum(renewable_energy, bioenergy(year, state, renewable_energy
* ghg_recycle(renewable_energy, ghg_gases) ) ;
```

The GAMS code below keeps track of GHG sinks for plantation trees. Researchers, thus, can study the impact of a carbon price on afforestation while excluding the other GHG emissions in the model.

```
carbon_tree_credit(year, state, ghg_gases)..

greenhouse_gases_trees(year, state, ghg_gases) =e= sum(type, hectares(year, state, type)
* trees_ghg(type, ghg_gases) );
```

9 Biosecurity

Use MAPGEM to investigate biosecurity risks.

9.1 Common Biosecurity Equations

9.2 Paddy

9.3 Palm Oil

9.4 Rubber

10 MAPGEM Input and Output

This chapter shows how users can change the parameters in MAPGEM, and how MAPGEM creates the output tables. The MAPGEM tables consist of the national, regional, and biosecurity. The national tables aggregate the variables across all states while the regional maintains forecasts at the state level. Finally, the biosecurity tables show the diagnostic tables to ensure the analysis of a pathogen's spread is not causing problems. Subsequently, MAPGEM outputs the files into HyperText Markup Language (HTML) files. The user should use the Opera browser to view the output files because the browser is light and does not overload the computer's resources. Opera can load the tables quickly especially for the regional tables since they are quite lengthy. The other browsers such as Microsoft Edge converts long numbers into phones and could take a while to load.

10.1 Input Parameters

The GAMS code declares the MAPGEM sets first, and then the parameters appear in the second section. The first section of parameters are the scalars. The variable name is black with the description in blue. The user can change the number between the green slashes. The last parameter is unique. The sensitivity is an on-off switch. If sensitivity is turned off, then MAPGEM defaults to the original population elasticities of demand. However, when the switch is turned on, MAPGEM switches all population elasticities to 1.25 to test the sensitivity of results to changes in the population.

```
Scalar   discount            discount rate                / 3.00 /
Scalar   land_change         Remove restrictions on ag land / 1.00 /
Scalar   crop_yield_growth   Percent growth in crop yields  / 0.50 /
Scalar   on_off_capacity     Turn on off renewable energy   / 0 /
Scalar   capacity_growth     Renewable energy capacity      / 5.00 /
Scalar   import_constraint   Multiple to limit imports      / 2.00 /
Scalar   export_constraint   Multiple to limit exports      / 2.00 /
Scalar   land_value          Terminal land value oil palms  / 5000.00 /
Scalar   sensitivity         Population Growth Sensitivity  / 0 /
```

The next set of inputs defines the parameters for taxes and duties. A user can impose the goods and services tax (GST) by entering the percent tax for domestic consumption, exports, and imports. The Malaysian government repealed the GST in 2018, but we left GST in the model in case the government re-implements it. Furthermore, Malaysia also imposes export and import duties, which come after the GST. Finally, a user can impose three forms of a carbon tax on greenhouse gas emissions. The carbon tax1 imposes a tax on all emissions in the model but becomes a subsidy for GHG sinks. The carbon tax2 imposes a carbon tax only on the reduced fossil fuel GHG that renewable energy replaces. Since renewable energy recycles GHG, the carbon tax becomes a subsidy. Finally, the carbon credit is the revenue landowners can earn by growing plantation trees. The plantation trees differ in their carbon storage potential with the rainforests storing the most carbon per hectare. The carbon price only applies to the quantity of carbon dioxide that plantation trees remove from the atmosphere to store in the trunks, branches, and roots.

```
Parameter   GST(demand_supply)      GST applied to goods & services
                                     / domestic 0.0, exports 0.0, imports 0.06 /
Parameter   duties(demand_supply)   GST applied to goods & services
                                     / domestic 0.0, exports 0.0, imports 0.05 /
Scalar      carbon_tax1             Carbon tax assessed on GHG                / 0.0 /
Scalar      carbon_tax2             Carbon tax assessed on renewable energy   / 0.0 /
Scalar      carbon_credit           Carbon credit for growing trees           / 0.0 /
```

Users can specify the exogenous prices for renewable energy. The first set of parameters turns on the selling of renewable energy with one as on and zero as off. The second set specifies the price for biodiesel, ethanol, and butanol, which equal RM per liter while bioelectricity is RM per kWh. Although flare methane shows in the parameters, palm oil mills do not earn revenue from flaring, which makes the price zero. The author simplified the GAMS code as much as possible, which includes the flaring of methane. At last, the government may pay a subsidy in the third set that is defined similarly as the price. The government could pay a subsidy to flare methane, in which case, the subsidy would equal RM per metric ton of methane.

```
  Parameter turn_on_energy(renewable_energy) 1 for on and 0 for off for exogenous energy prices
 biodiesel       1,
 bioelectricity  1,
 butanol         1,
 ethanol         1,
 acetone         1,
 flare           1

  Parameter energy_prices(renewable_energy) Exogenous energy prices
 biodiesel       1.00,
 bioelectricity  0.20,
 butanol         1.00,
 ethanol         1.00,
 acetone         1.9082,
 flare           0.00

  Parameter energy_subsidy(renewable_energy) Gov.  subsidizes bio-energy
 biodiesel       0.00,
 bioelectricity  0.00,
 butanol         0.00,
 ethanol         0.00,
 acetone         0.00,
 flare           0.00
```

The user, at last, can impose minimum fuel mandates for renewable energy. Similar to prices, the user can turn on a mandate for a particular bioenergy by entering a one while a zero turns off the mandate. Then the user enters the percentage the mandate specifies in the next set. For example, a B10 for biodiesel requires the transportation sector to blend a minimum of 10% of biodiesel with diesel. The user would enter a 10 for biodiesel. The minimum fuel mandate has three caveats. First, the user should also turn on the price for the specified bioenergy and enter a price. Otherwise, the mandate forces producers to provide the bioenergy for free. Second, a user should only impose one mandate at a time because butanol, ethanol, and bioelectricity compete for the same waste biomass. Thus, it may not be feasible to study a variety of mandates at the same time. Finally, a lack of resources may not satisfy the mandate. Hence, GAMS will fail to find an optimal solution.

```
  Parameter turn_on_mandate(renewable_energy) 1 turns on and 0 turns off
 biodiesel       0,
 bioelectricity  0,
 butanol         0,
 ethanol         0,
 acetone         0,
 flare           0

  Parameter min_fuel_mandate(renewable_energy) Percentage industry must supply
 biodiesel       10.0,
 bioelectricity  0.00,
 butanol         0.00,
 ethanol         10.0,
 acetone         0.0,
 flare           0.00
```

10.2 Calculations

MAPGEM calculates new variables from the model after it finds the optimal solution that maximizes consumers' plus producers' surpluses, For example, MAPGEM does not contain equations to calculate domestic, export, import, and resource prices because the social welfare function embeds prices implicitly. MAPGEM calculates the price for each commodity from its demand function by inserting the parameters and variables in Equation 68. $C_{i,t}$ is the optimal domestic consumption for commodity (i) at time (t). MAPGEM calculates import, export, and resource prices similarly. Of course, resource prices also include a subscript for a state (s).

$$P_{i,t}\left(C_{i,t}\right) = a_i C_{i,t}^{b_i} POP_t^c \left(1 + duty\right)\left(1 + GST\right) \tag{68}$$

The production variables occur at the state level, so MAPGEM aggregates them to the national level to show in the national output HTML file. For instance, Equation 69 shows aggregate production (AP) by summing a commodity (i) produced (SP) in each (s) for time (t). MAPGEM also aggregates bioenergy outputs and inputs, resources, cropland, plantation land, land conversion, and GHG emissions at the national level.

$$AP_{t,i} = \sum_s SP_{t,s,i} \tag{69}$$

MAPGEM computes a weighted average of the resource prices in Equation 70. The bar indicates the weighted average, which equals the sum of resource prices (RP) times the resources used (RU) in each state (s) at the time (t) divided by the total resources in time (t). MAPGEM includes labor, nitrogen, phosphorous, and potash.

$$\overline{RP}_{t,r} = \frac{\sum_s RP_{t,s,r} \cdot RU_{t,s,r}}{\sum_s RU_{t,s,r}} \tag{70}$$

Equations 71 - 73 show how MAPGEM calculates the Laspeyres, Paasche, and Fisher indices for domestic consumption (C). The Laspeyres uses the 2015 domestic consumption as the basket of goods while the Paasche uses current domestic consumption. The numerator for both indices is the value of domestic consumption divided by the base year, 2015. The Laspeyres tends to overestimate the price index for goods for price increases while the Paasche underestimates it. The Fisher index is the geometric average of the Laspeyres and Paasche indices and considered a more accurate measure of the price index. The geometric average smooths the over and under estimates of the Laspeyres and Paasche indices. MAPGEM outputs all three indices and also computes price indices for imports and exports similarly.

$$Laspeyres\ Index_t = 100 \cdot \frac{\sum_i P_{t,i} \cdot C_{2015,i}}{\sum_i P_{2015,i} \cdot C_{2015,i}} \tag{71}$$

$$Paasche\ Index_t = 100 \cdot \frac{\sum_i P_{t,i} \cdot C_{t,i}}{\sum_i P_{2015,i} \cdot C_{t,i}} \tag{72}$$

$$Fisher\ Index_t = \sqrt{Laspeyres\ Index_t \cdot Paasche\ Index_t} \tag{73}$$

MAPGEM, at last, computes the aggregate value of all commodities. Equation 74, for example, shows the cumulative value of domestic consumption (C), which equals a commodity's price (P) times the amount consumed for the commodity (i). The $Value_t$ removes the impact of changing prices by using 2015 prices for all time periods. MAPGEM calculates export and import values similarly. MAPGEM also calculates the aggregate production value of all commodities by adding the value of domestic consumption plus exports and renewable energy sold to the fossil energy sectors minus imports.

$$Value_t = \sum_i P_{2015,i} \cdot C_{t,i} \tag{74}$$

10.3 National Tables

MAPGEM creates three HTML files for the national aggregates, detailed state-level numbers, and the biosecurity diagnostic tables. Table 10.1 shows the current tables available in MAPGEM. As needs change, researchers can add or remove tables from the output files. MAPGEM currently has 24 national tables because most of the research and analyses focus on national impacts. The current research is utilizing the biosecurity tables to study a pathogen's impact on oil palms, rubber, and paddy.

All HTML files have an opening and closing statements, <html> and </html>. MAPGEM places document information between the <head> and </head> tags while the tables and data lie between the <body> and </body> tags. Every table has a number and a caption at the top that correspond to the entries in Table 10.1. Every line uses a put statement that writes the command to the output file. A slash, /, continues the put command while a semicolon ends it. The line, <p> </p>, places vertical spacing between tables using the paragraph tags while   places a blank space on a text line. The <h1> and </h1> print the section headings while table captions are formed using the heading 2, <h2> and </h2>, tags.

Users can manipulate the HTML tags on each web page using cascading style sheets (CSS). For example, users can define which fonts and sizes to apply to headings and table captions. Furthermore, the CSS contains a table collapse function that removes the spacing between cells. That way, the code places beautiful connecting lines at the top and bottom of the tables. The CSS, at last, allows the tables to share a similar format and look.

Every HTML table requires three attributes. The tags, <table> and </table>, enclose a table. Meanwhile, the tags, <tr> and </tr> define a row while the <td> and </td> define particular cells in a row. MAPGEM uses two table constructions. A normal table sandwiches the table headings and years between horizontal lines. The first loop calculates the years manually because the set for years has a y as part of the year label. Subsequently, a nested loop follows that outputs the variable's name and year. The command, type.te, extracts the names from the variable in the order the set is defined. The nested loop contains if and else statements because when the loop reaches the last entry in the set, the code places a horizontal line at the bottom of the table. Then the loop closes and ends the table construction. A table may contain notes at the bottom sandwiched between the paragraph tags, <p> and </p>. The programming uses a trick by using the conditional statement, $(card(year) - ord(year) > 0). The card command refers to the last index for a year while the ord refers to any year index. Thus, the conditional statement prevents the output of the last year results as a way to get away from the terminal condition. The statement, if (ord(type) < card(type), is similar and allows the placement of a horizontal line at the bottom of the table.

```
   put / '<p> </p>'
/ '<h2>Table 11.  Labor Employed in Plantations (workers)</h2>'
```

Table 10.1: MAPGEM Tables

	National	Regional	Biosecurity
Table 1	Domestic Prices	Regional Resource Prices	Pathogen Presence
Table 2	Export Prices	Regional Production	Infection Spreads
Table 3	Import Prices	Regional Resource Use	Newly Infected Land
Table 4	Resource Prices	Regional Cropland	Total Good Land Remaining
Table 5	Aggregate Production	Regional Plantation Land	Total Infected Land
Table 6	Domestic Consumption	Regional Land Change	Recovered Land
Table 7	Exports	Biofuel Feedstocks	Percentage of Infected Land
Table 8	Imports	Regional Biofuel Production	
Table 9	Resource Usage		
Table 10	Labor Employed in Crops		
Table 11	Labor Employed in Plantations		
Table 12	Aggregate Cropland		
Table 13	Aggregate Plantation Land		
Table 14	The Growth of Oil Palm Plantations		
Table 15	Feedstocks for Bioenergy		
Table 16	Bioenergy Production		
Table 17	Total GHG Emissions		
Table 18	Bioenergy GHG		
Table 19	GHG Emissions from Land Change		
Table 20	Crop Sequestration of GHG		
Table 21	Plantation Sequestration of GHG		
Table 22	GHG Emissions from Resources		
Table 23	GHG Emissions from Commodities		
Table 24	MAPGEM Calibration		

```
/ '<table>'
/ '<tr class="border_bottom_top">'
/ ' <td>Resource</td>' ;
Loop (year$(card(year) - ord(year) > 0 ),
proper_year = 2010+5*ord(year);
put / ' <td style="text-align:  center;">' proper_year '</td>' ;
);
put / '</tr>' ;
Loop (type,
if (ord(type) < card(type),
put / '<tr>'
/ '<td>' type.te(type) '</td>' ;
else
put / '<tr class="border_bottom">'
/ ' <td>' type.te(type) '</td>') ;
Loop (year$(card(year) - ord(year) > 0 ),
put / ' <td style="text-align:  center;">' aggregate_labor_plantation(year, type) '</td>' ;
) ;
put / '</tr>' ;
) ;
put / '</table>'
/ '<p> </p>' ;
```

The next table shares similarities with the previous table except for some tables insert new data at the end of the table. For example, the table below adds three price indices: Laspeyres, Paasche, and Fisher. The table includes simple loops for each price index and the line declaration, <tr>, includes a horizontal line. At last, the production table includes the aggregate value of production of all commodities for every year and the social welfare. Similarly, domestic consumption, export, and import tables also add their own aggregate production values.

```
   put / '<p> </p>'
/ '<h2>Table 1.  Domestic Prices (RM per ton)</h2>'
/ '<table>'
/ '<tr class="border_bottom_top">'
/ ' <td>Commodity</td>' ;
Loop (year$(card(year) - ord(year) > 0 ),
proper_year = 2010+5*ord(year);
put / ' <td style="text-align:  center;">' proper_year '</td>' ;
);
put / '</tr>' ;
Loop (commodities,
put / '<tr>'
/ '<td>' commodities.te(commodities) '</td>' ;
Loop (year$(card(year) - ord(year) > 0 ),
put / ' <td style="text-align:  center;">' price_domestic(year, commodities) '</td>' ;
) ;
put / '</tr>';
) ;
put / '<tr>'
/ ' <td>laspeyres Price Index</td>' ;
Loop (year$(card(year) - ord(year) > 0 ),
put / ' <td style="text-align:  center;">' index_laspeyres_domestic(year) '</td>' ;
) ;
put / '</tr>'
/ '<tr>'
/ ' <td>paasche Price Index</td>' ;
Loop (year$(card(year) - ord(year) > 0 ),
put / ' <td style="text-align:  center;">' index_paasche_domestic(year) '</td>' ;
) ;
put / '</tr>'
/ '<tr class="border_bottom">'
/ ' <td>Fisher Price Index</td>' ;
Loop (year$(card(year) - ord(year) > 0 ),
```

```
put / ' <td style="text-align:  center;">' index_fisher_domestic(year) '</td>' ;
) ;
put / '</tr>'
/ '</table>'
/ '<p><b>Note:  </b>Year 2015 establishes the base year for the price indices.  '
/ '<p> </p>' ;
```

10.4 Regional Tables

The HTML code shares similarities with the code to construct national tables. The regional tables, of course, omit aggregate measures like production value and price indices. The GAMS code below shows the code for regional resource prices. The first loop outputs the heading for the year with the y removed from the year's label. Subsequently, three nested loops output a variable, starting with the resource price, the year, and then the state. The code contains if .. then statements to control the placement of borders. Two horizontal lines sandwich the year heading while the last state in a list has a border below.

```
   put / '<p> </p>'
/ '<h2>Table 1.  Regional Resource Prices (RM per unit)</h2>'
/ '<table>'
/ '<tr class="border_bottom_top">'
/ ' <td>Resource and State</td>' ;
Loop (year,
proper_year = 2010+5*ord(year);
put / ' <td style="text-align:  center;">' proper_year '</td>' ;
);
put / '</tr>' ;
Loop (resources,
put / '<tr>'
/ ' <td><b>' resources.te(resources) '</b></td>';
Loop (year,
put / ' <td style="text-align:  center;"> </td>' ;
);
put / '</tr>';
Loop (state,
if (ord(state) < card(state),
put / '<tr>'
/ ' <td>' state.te(state) '</td>';
else
put / '<tr class="border_bottom">'

/ ' <td>' state.te(state) '</td>' );
Loop (year,

put / ' <td style="text-align:  center;">' price_resource_region(year, state, resources) '</td>'
;
) ;
put / '</tr>' ;
) ;
);
put / '</table>'
/ '<p><b>Note:</b> Wages are annual salary.  Fertilizer is RM per ton.</p>'
/ '<p> </p>' ;
```

10.5 Biosecurity Tables

The biosecurity tables are the easiest to construct because the biosecurity tables only contain the state and year. To study biosecurity issues, we modify MAPGEM to analyze the impact of a pathogen on paddy, rubber, and oil palms.

```
   put / '<p> </p>'
/ '<h2>Table 1 Indicator Function to Signal Presence of Biohazard</h2>'
/ '<table>'
/ '<tr class="border_bottom_top">'
/ ' <td>State</td>' ;
Loop (year$(card(year) - ord(year) > 0 ),
proper_year = 2010+5*ord(year);
put / ' <td style="text-align:  center;">' proper_year '</td>' ;
);
put / '</tr>' ;
Loop (state,
if (ord(state) < card(state),
put / '<tr>'
/ '<td>' state.te(state) '</td>' ;
else
put / '<tr class="border_bottom">'
/ ' <td>' state.te(state) '</td>') ;
Loop (year$(card(year) - ord(year) > 0 ),
put / ' <td style="text-align:  center;">' state_infected(year, state) '</td>' ;
) ;
put / '</tr>' ;
) ;
put / '</table>'
/ '<p><b>Note:  </b>Indicates whether a state has the infection.  '
/ '<p> </p>' ;
```

11 Appendix - Fertilizer Usage

Food and Agriculture Organization of the United Nations [2004] supplies all fertilizer data except kenaf. The fertilizer information is placed in the table, crop_resources(state, crops, resources), for crops and plantation_resources(state, type, resources) for plantation trees.

Table 11.1: Banana

State	Nitrogen tons / hectare	Phosphorous tons / hectare	Potash tons / hectare
Johor	0.4428	0.4428	0.5434
Kedah	0.3010	0.3010	0.3687
Kelantan	0.1722	0.1722	0.2112
Melaka	0.2703	0.2703	0.3311
Negeri Sembilan	0.1272	0.1272	0.1572
Pahang	0.1729	0.1729	0.2121
Perak	0.2338	0.2338	0.2871
Perlis	0.0455	0.0455	0.0455
Penang	0.1886	0.1886	0.2312
Selangor	0.1495	0.1495	0.1834
Terengganu	0.1754	0.1754	0.2150
Sabah	1.7690	1.7690	2.1719
Sarawak	0.2110	0.2110	0.2591
Average	0.2691	0.2691	0.3302

Table 11.2: Cocoa

state	Nitrogen tons / hectare	Phosphorous tons / hectare	Potash tons / hectare
West Malaysia	0.1774	0.0828	0.2128
Sabah	0.1383	0.0645	0.1659
Sarawak	0.0381	0.0178	0.0458
Average	0.1277	0.0595	0.1531

Table 11.3: Coconut

state	Nitrogen tons / hectare	Phosphorous tons / hectare	Potash tons / hectare
West Malaysia	0.0136	0.0177	0.0136
Sabah			
Sarawak	0.0215	0.0280	0.0215
Average	0.0125	0.0157	0.0125

Table 11.4: Durian

State	Nitrogen tons / hectare	Phosphorous tons / hectare	Potash tons / hectare
Johor	0.0341	0.0341	0.0525
Kedah	0.0238	0.0238	0.0365
Kelantan	0.0152	0.0152	0.0234
Melaka	0.0257	0.0257	0.0396
Negeri Sembilan	0.0218	0.0218	0.0334
Pahang	0.0160	0.0160	0.0247
Perak	0.0163	0.0163	0.0251
Perlis	0.0141	0.0141	0.0282
Penang	0.0161	0.0161	0.0249
Selangor	0.0158	0.0158	0.0244
Terengganu	0.0168	0.0168	0.0258
Sabah			
Sarawak	0.0218	0.0218	0.0337
Average	0.0233	0.0233	0.0359

Table 11.5: Kenaf

state	Nitrogen tons / hectare	Phosphorous tons / hectare	Potash tons / hectare
Average	0.08 – 0.10	0.15 – 0.20	0.10

Source: Came from Basri et al. [2014]

Table 11.6: Mango

State	Nitrogen tons / hectare	Phosphorous tons / hectare	Potash tons / hectare
Johor	0.0174	0.0174	0.0265
Kedah	0.0148	0.0148	0.0227
Kelantan	0.0166	0.0166	0.0253
Melaka	0.0129	0.0129	0.0198
Negeri Sembilan	0.0219	0.0219	0.0337
Pahang	0.0199	0.0199	0.0308
Perak	0.0276	0.0276	0.0425
Perlis	0.0137	0.0137	0.0211
Penang	0.0110	0.0110	0.0176
Selangor	0.0107	0.0107	0.0162
Terengganu	0.0015	0.0015	0.0022
Sabah			
Sarawak	0.0093	0.0093	0.0142
Average	0.0145	0.0145	0.0223

Table 11.7: Oil Palm

state	Nitrogen tons / hectare	Phosphorous tons / hectare	Potash tons / hectare
Johor	0.2422	0.2725	0.3785
Kedah	0.2214	0.2491	0.3460
Kelantan	0.1864	0.2096	0.2912
Melaka	0.2903	0.3265	0.4535
Negeri Sembilan	0.2511	0.2825	0.3924
Pahang	0.2314	0.2604	0.3616
Perak	0.2751	0.3095	0.4299
Penang	0.2342	0.2634	0.3659
Perlis			
Selangor	0.2487	0.2798	0.3886
Terengganu	0.1778	0.2000	0.2778
Sabah	0.2633	0.2962	0.4113
Sarawak	0.1710	0.1923	0.2671
Average	0.2391	0.2690	0.3736

Table 11.8: Papaya

State	Nitrogen tons / hectare	Phosphorous tons / hectare	Potash tons / hectare
Johor	0.0096	0.0096	0.0135
Kedah	0.0007	0.0007	0.0010
Kelantan	0.0034	0.0034	0.0045
Melaka	0.0095	0.0095	0.0138
Negeri Sembilan	0.0138	0.0138	0.0200
Pahang	0.0018	0.0018	0.0025
Perak	0.0841	0.0841	0.1191
Perlis			
Pulau	0.0073	0.0073	0.0095
Selangor	0.0028	0.0028	0.0039
Terengganu	0.0054	0.0054	0.0069
Sabah	0.0059	0.0059	0.0084
Sarawak	0.0030	0.0030	0.0043
Average	0.0125	0.0125	0.0177

Table 11.9: Pepper

State	Nitrogen tons / hectare	Phosphorous tons / hectare	Potash tons / hectare
West Malaysia			
Sabah			
Sarawak	0.0875	0.0394	0.1203
Average			

Table 11.10: Pineapple

State	Nitrogen tons / hectare	Phosphorous tons / hectare	Potash tons / hectare
Johor	0.2485	0.2485	0.2944
Kedah	0.0992	0.0992	0.1157
Kelantan	0.1056	0.1056	0.1232
Melaka	0.2500	0.2500	0.2500
Negeri Sembilan	0.1364	0.1364	0.1515
Pahang	0.0400	0.0400	0.0400
Perak	0.0532	0.0532	0.0532
Penang	0.1111	0.1111	0.1327
Selangor	0.1989	0.1989	0.2376
Terengganu			
Sabah	0.0616	0.0616	0.0729
Sarawak	0.1060	0.1060	0.1259
Average	0.1866	0.1866	0.2212

Table 11.11: Rambutan

State	Nitrogen tons / hectare	Phosphorous tons / hectare	Potash tons / hectare
Johor	0.0619	0.0619	0.0874
Kedah	0.0721	0.0721	0.1019
Kelantan	0.0441	0.0441	0.0627
Melaka	0.0615	0.0615	0.0879
Negeri Sembilan	0.0852	0.0852	0.1215
Pahang	0.0278	0.0278	0.0395
Perak	0.0299	0.0299	0.0422
Perlis	0.0196	0.0196	0.0392
Penang	0.0299	0.0299	0.0425
Selangor	0.0728	0.0728	0.1038
Terengganu	0.0533	0.0533	0.0753
Sabah	0.0355	0.0355	0.0506
Sarawak	0.0381	0.0381	0.0540
Average	0.0470	0.0470	0.0665

Table 11.12: Rice

State	Nitrogen tons / hectare	Phosphorous tons / hectare	Potash tons / hectare
Johor	0.1682	0.0614	0.0439
Kedah	0.1989	0.0767	0.0548
Kelantan	0.0036	0.0015	0.0011
Melaka	0.1650	0.0463	0.0331
Negeri Sembilan	0.6379	0.2308	0.1652
Pahang	2.7569	1.0258	0.7324
Perak	0.1178	0.0458	0.0327
Perlis	0.2488	0.1033	0.0738
Penang	0.2024	0.0787	0.0563
Selangor	0.2583	0.1005	0.0717
Terengganu	0.1685	0.0656	0.0468
Sabah	0.1787	0.0695	0.0496
Sarawak	0.0592	0.0230	0.0164
Average	0.1661	0.0646	0.0461

Table 11.13: Rubber Tree

State	Nitrogen tons / hectare	Phosphorous tons / hectare	Potash tons / hectare
Johor	0.2167	0.3236	0.5550
Kedah and Perlis	0.2216	0.3308	0.5674
Kelantan	0.1913	0.2856	0.4900
Melaka	0.1838	0.2745	0.4710
Negeri Sembilan	0.2547	0.3802	0.6523
Pahang	0.2243	0.3348	0.5744
Perak	0.2648	0.3952	0.6780
Penang			
Selangor	0.1767	0.1722	0.4528
Terengganu	0.1484	0.1474	0.3800
Sabah and Sarawak	0.1209	0.1178	0.3100
Average	0.2206	0.2148	0.5650

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