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# THE POTENTIAL OF BIOELECTRICITY IN MALAYSIA

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**ABSTRACT**

Malaysia relies on coal and natural gas to generate its electricity. Fossil fuels, nevertheless, are unsustainable with reserves lasting up to 60 years. Furthermore, the fossil fuels emit significant levels of carbon dioxide that absorb infrared energy from the sun and heat the earth's surface, leading to global warming and climate change. Thus, this paper investigates whether bioelectricity from ag wastes can reduce fossil fuel usage and mitigate carbon dioxide emissions. Furthermore, bioelectricity could lengthen the natural gas and coal reserves and also recycles carbon from the atmosphere via plants and trees. This paper uses a dynamic, endogenous price model, called the Malaysian Agricultural and Plantation Greenhouse Gas Equilibrium Model (MAPGEM) to quantify how much bioelectricity palm oil mills could generate. MAPGEM forecasts 50 years into the future and predicts the imports, exports, domestic consumption, and prices for Malaysia's primary agricultural commodities, such as banana, cocoa, coconut, durian, kenaf, mango, oil palm, papaya, pepper, pineapple, rambutan, rubber, and rice. MAPGEM includes the ag wastes and byproducts from the agriculture industry. At last, MAPGEM indicates the palm oil mills can supply 72.165 gigawatt-hours (GWh) of bioelectricity in 2020 that expands to 87.672 GWh in 2065 if mills charge RM0.40 per kilowatt-hour (kWh). At a bioelectricity price of RM0.60 per kWh, mills generate bioelectricity from collecting methane from palm oil mill effluents. MAPGEM also indicates the mills could supply 15% of the nation's electricity from bioelectricity if the government were to impose a minimum bioelectricity mandate.

**Keywords:** Endogenous price model; bioelectricity, palm oil mills, and Malaysian Agricultural and Plantation Greenhouse Gas Equilibrium Model

## 1.0 Introduction

Malaysia relies on coal and natural gas to generate electricity. It generated approximately 123,076 gigawatt-hours (GWh) of electricity in 2013, which equaled 4,114 kilowatt-hours (kWh) per capita (Suruhanjaya Tenaga, 2015). On the peninsula, the energy industry generates approximately 53.0% from coal and 42.5% from natural gas (Green Tech Malaysia, 2013). Both coal and natural gas are depletable resources and unsustainable. Muda and Pin (2012), for example, predicts Malaysia has 52 years of natural gas reserves and 64 years of coal reserves. Once the reserves run out, Malaysia will either adopt a new technology or import natural gas and coal. Importation, alas, leads to an outflow of funds and reduces trade surpluses.

The burning of coal and natural gas inflicts a societal problem by releasing significant sources of carbon dioxide into the atmosphere. Carbon dioxide is a greenhouse gas that absorbs more thermal infrared energy in the atmosphere, leading to the greenhouse effect. The earth's surface gradually warms while the climate changes. Accordingly, 192 countries signed the Kyoto Protocol in 1997 and pledged to slow global warming by curtailing their greenhouse gas emissions. Although Malaysia signed the Kyoto Protocol, the agreement does not impose quantitative restrictions on Malaysia to reduce its greenhouse gas emissions.

Renewable energy can slow the consumption of fossil fuels and reduce greenhouse gas emissions. If Malaysia could produce a significant proportion of its electricity from wastes, it slows the consumption of coal and natural gas and lengthens the life of reserves. The Malaysian agricultural industry creates a massive amount of wastes from palm fronds, empty fruit bunches, rice husks, rice straw, coconut shells, and methane from palm oil mill effluent ponds. Palm oil mills could collect the wastes and burn them to generate bioelectricity. Furthermore, wastes originating from agriculture are recycled carbon dioxide from the atmosphere. Bioelectricity, consequently, lowers greenhouse gas emissions and could reduce Malaysia's carbon footprint in the world.

The authors believe MAPGEM is the first comprehensible model in Malaysia to examine renewable energy potential from Malaysian agriculture and plantations. The model predicts for a bioelectricity price of RM0.40 per kWh; the palm oil mills can generate 72,165.13 million kilowatt hours (kWh) in 2020 that grows to 87,672.10 million kWh in 2065. Malaysians pay about RM0.38 per kWh on the peninsula for electricity. At a price of RM0.60 per kWh, the mills generate bioelectricity from the methane from palm oil mill effluents. Finally, palm oil mills could supply 15% of the electricity from ag wastes if the government were to impose a minimum bioelectricity mandate. The next section covers the literature review.

## 2.0 Literature Review

The research in Malaysia has focused on the oil palm plantations using supply chain simulations, For example, Henson (2009), and Chase and Henson (2010) develop the Oil Palm Carbon Budget Simulator (OPCABSIM) and Global Warming Assessment of Palm oil Production (GWAPP) model, which simulates Malaysian palm oil mills. The models track greenhouse gas emissions and the carbon sequestration of plantation trees. Finally, the Roundtable on Sustainable Palm Oil (2017) develop a greenhouse gas calculator for oil palm mills which mill operators can download the software, PalmGHG, for free. Operators enter the parameters of their palm oil plantations and processing plants, and PalmGHG estimates the mill's carbon emissions. That way, managers can develop strategies to lower GHG emissions and their carbon footprint.

Simulation models can estimate supply chains accurately, but the models may lack market dynamics and dynamic forecasts. MAPGEM overcomes this deficiency and also includes Malaysia's major commodities. MAPGEM is based on the U.S. model – Forest and Agricultural Sector Optimization Model with Greenhouse Gases (FASOMGHG). It is a dynamic, endogenous price model that contains 63 production regions and numerous forestry, crop, and livestock products. Maung and McCarl (2013) utilize FASOMGHG to study the potential for crop residues to generate bioelectricity while Szulczyk, McCarl, and Cornforth (2010) and Szulczyk and McCarl (2010) study the market penetration of ethanol and biodiesel in the U.S. transportation fuel markets. The next section introduces the features of MAPGEM.

## 3.0 Method and Model Description

The Malaysian Agricultural and Plantation Greenhouse Gas Equilibrium Model (MAPGEM) is a dynamic, endogenous price model written in the General Algebraic Modeling System (GAMS). The model maximizes consumers' plus producers' surpluses over time (t), which originates from the inverse demand and supply functions in Equation (1). Each commodity (i) has a domestic consumption (C) and export (E) inverse demands, and import (I) inverse supply. Furthermore, MAPGEM includes inverse supply functions for resources used (RU) at the state (s) level with four types of resources (r): Labor, nitrogen, phosphorus, and potash. The * denotes the optimal level of consumption, exports, imports and resources used that maximize B with δ as the discount rate. The notation, P(C), denotes price is a function of consumption while the other price functions have the same construction. The demand and supply functions are nonlinear with constant elasticities. Table 1 shows all the commodities in MAPGEM that include the ag wastes and byproducts. The other terms in Equation (1) include growing, processing, and harvesting costs, revenue from renewable energy, and carbon taxes. Finally, the objective function includes terminal conditions (TC) for palm oil plantations since land owners would not develop new land in 2065 because they cannot harvest newly planted oil palm trees.

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

Figure 1 shows the domestic consumption, exports, and imports on the right in red boxes while resources used is on the left side in a green box. MAPGEM connects resources to the demand by using 30 blocks of equations. The model begins in 2015 (t=1) and forecasts 50 years into the future in five-year increments while population growth increases the demand functions over time. The production, prices, domestic consumption, exports, and imports are aligned to 2015 quantities such as national production statistics from Jabatan Perangkaan Malaysia (2016).

Figure 1 shows MAPGEM splits agricultural commodities into crops and plantations. The crops include banana, durian, kenaf, mango, papaya, pepper, pineapple, rambutan, and rice while plantations include cocoa, coconut, forest, palm oil, and rubber trees. Although crops comprise of several trees, the trees grow rapidly in five years. Subsequently, farmers and plantation owners use labor and fertilizer to grow crops and trees.

Labor harvests the crops and plantations and feeds them into the production possibilities. Equation (2) shows the input possibilities for plantations. Hectares (H) denotes the total hectares for plantations (p) that include cocoa, coconut, forest, palm oil, and rubber. The plantation yield (PY) times the hectares equal the amount harvested in time (t) and state (s). The combine (COM) matrix and plantation (p1) set merges the harvests of fresh fruit bunches for five-year-old and mature oil palms. Then the decision variable, plantation input (PI), allocates each metric ton of harvest to a process, while manufacture input (MI) determines how much input is required for each process.

$$\sum_{process} MI_{p,process} \cdot PI_{t,s,process} \le \sum_{p1} COM_{p,p1} \cdot PY_{s,p1} \cdot H_{t,s,p1} \tag{2}$$

Equation (3) shows the production possibilities for the joint products for plantations. The quantities of joint plantation products (pp) equal the plantation input (PI) times the manufacturing output (MO) matrix. For example, MAPGEM contains three production possibilities for palm oil. Palm oil mills process fresh fruit bunches into palm oil, empty fruit bunches (EFB), methane emitted from palm oil mill effluent (POME) ponds, palm fiber, palm frond, palm kernel cake, palm kernel oil, palm oil, palm shell, and palm fatty acid distillates (PFAD). The second palm oil possibilities convert palm oil to palm biodiesel while the third collects yellow grease from the food industry. At last, the producers either transfer (T) the commodities to the renewable energy possibilities or ship them to production (PD) that feeds into domestic consumption and export demands. Crops and renewable energy also have their own production possibilities for joint production.

$$\sum_{process} MO_{pp,process} \cdot PI_{t,s,process} = PD_{t,s,pp} + T_{t,s,pp} \quad (3)$$

The plantations consist of dynamic equations, which Equation (4) shows. For example, the hectares (H) for rubber at the time (t) in the state (s) equals the previous period rubber tree hectares minus the land converted (CN) to palm oil plantations. The converted land comes from the prior period because plantation owners would harvest the latex at time t before clearing the land for the next period. In the year 2015 (t=1), MAPGEM loads the inventory of rubber trees from the plantation (PL) matrix. The $\phi$ is an indicator function which equals 0 or 1. Subsequently, plantation owners can shift cocoa, coconut, and forest into palm oil plantations, and they have their own similar dynamic equations. Finally, palm oil has three sets of equations. The newly planted palm oil plantations take cleared land and plant new oil palms. Then the land passes to the five-year-old palm trees, and eventually stop at the mature palm oil trees.

$$H_{t,s,rubber} = H_{t,s,rubber} \cdot \emptyset(t > 1) - CN_{t-1,s,rubber} \cdot \emptyset(t > 1) + PL_{s,rubber} \cdot \emptyset(t = 1) \quad (4)$$

MAPGEM comprises of about 28,000 equations that represent state-level production and capture a state's unique growing and economic conditions. Farmers and plantation owners experience different crop and tree yields because of various soil types, rainfall, and other growing conditions. Producers in a state, furthermore, apply different amounts of nitrogen, phosphorous, and potash, and they also differ in labor productivities. Finally, states differ in growing costs for crops and trees, but not enough information was found from the literature to exploit this.

MAPGEM's key feature is the renewable energy production possibilities, which consists of 32 different processes. The palm oil mills, for instance, uses three processes for biodiesel: palm oil biodiesel, PFAD biodiesel, and yellow grease biodiesel. In addition, palm oil mills can ferment the agricultural wastes and byproducts into ethanol or butanol that substitute for petrol fuel or combust the wastes to generate bioelectricity. Ethanol and butanol each have nine processes that depend on a specific feedstock while bioelectricity has 10[22]. At last, palm oil mills can collect the methane from POME. They either flare the methane to produce carbon dioxide or burn it to generate bioelectricity. Palm oil mills would be at the center of renewable energy because the palm oil industry generates approximately 95% of the waste products.

MAPGEM allows researchers to study a variety of renewable energy prices and government policies. First, users can specify the exogenous prices for biodiesel, ethanol, butanol, and bioelectricity. The corresponding fossil fuel markets are much larger than the agriculture markets while the Malaysian government sets the prices for electricity and transportation fuels. For example, producers of bioelectricity receive a feed-in tariff for electricity. Second, MAPGEM contains an inventory of greenhouse gas emissions for activities that emit or sequester carbon dioxide, nitrous oxide, and methane. Users can study carbon taxes and credits and their economic impact. Finally, MAPGEM allows researchers to examine minimum fuel mandates and subsidies. The next section uses MAPGEM to predict how much bioelectricity the palm oil mills can supply and its economic impact.

[22] In MAPGEM, mills generate bioelectricity from direct combustion, but MAPGEM does allow integrated gas combined cycle (IGCC) that has a higher thermal conversion efficiency and greater capital costs.

## 4. 0 Results And Discussion

Figure 2 and Table 2 show how much bioelectricity the agricultural industry can supply by varying the price between RM0.20 and RM0.80 per kilowatt-hour (kWh). For RM0.20 per kilowatt-hour (kWh), palm oil mills supply zero bioelectricity because the operating and capital costs exceed the revenue. When electricity price rises to RM0.40, mills begin supplying bioelectricity starting at 72.2 billion kWh in 2020 and ending 87.7 kWh in 2065. Malaysians pay about RM0.40 per kilowatt-hour (kWh), and the Sustainable Energy Development Authority Malaysia (2017) estimated palm oil mills generated 12.332 million kWh in 2017. Furthermore, mills utilize all agricultural wastes to produce electricity except methane. When bioelectricity price rises to RM0.60 per kWh, producers install the capital to collect methane from palm oil mill effluent ponds and burn it to produce bioelectricity. At RM0.80, palm oil mills expand production to collect more ag wastes to generate electricity since bioelectricity has become more profitable. Although ag wastes are a byproduct of production, the wastes become valuable as mills boost electricity generation by growing more oil palms and ag commodities that create wastes.

The MAPGEM results seem overly optimistic in bioelectricity generation. Pusat Tenaga Malaysia estimates palm oil mills can generate 2,000MW from biomass and biogas in 2005 (Oh & Chua, 2010). However, MAPGEM estimates exceed Pusat Tenaga Malaysia by five times. MAPGEM starts in 2015 with 5.6 million hectares of oil palms while Pusat Tenaga Malaysia's study had about 4 million hectares in 2005. Finally, MAPGEM also includes ag wastes from banana, coconut, pineapple, and paddy.

Figure 3 and Table 3 show the impact of bioelectricity prices on production value in constant prices. The value of output starts at RM78 billion and grows to RM86.7 billion in 2020 for electricity price of RM0.20 kWh. As the electricity price rises to RM0.40 kWh, the electricity production climbs to RM116.2 billion in 2020, an RM29.4 billion increase. An electricity price exceeding RM0.40 kWh leads to greater profits and a transfer of income from society to the agriculture industry.

Figure 4 and Table 4 show the domestic price index. Palm oil mills supply zero bioelectricity at RM0.20 kWh while the price index decreases over time as the palm oil plantations expand and supply more commodities relative to a rising population. For a bioelectricity price exceeding RM0.40 kWh, the agriculture sector expands supply relative to demand. Farmers grow more bananas and pineapple to provide ag wastes to the palm oil mills, so that they can produce more bioelectricity. Moreover, rice farmers slow the conversion of paddy fields to other crops since they also supply rice straw and rice husks to the palm oil mills.

Figure 5 and Table 5 show the aggregate land transfers from forests and cocoa, coconut, and rubber plantations to palm oil plantations. The conversion of forests into palm oil comprises the largest land transfer. The bioelectricity price has little impact on land use conversion. The palm oil plantations expand greatly at first to meet rising domestic and export demands and taper over time. Expanding oil palm plantations generate more wastes that palm oil mills collect to produce bioelectricity.

Figure 6 and Table 6 show how much renewable energy can recycle greenhouse gases from biodiesel, butanol, ethanol, and bioelectricity. The 100-year global warming potential (GWP) converts methane and nitrous oxide into carbon equivalents. Methane has a GWP of 25 while nitrous oxide with 298 (Intergovernmental Panel on Climate Change, 2007). Consequently, one metric ton of nitrous oxide absorbs the same thermal energy as 298 tons of carbon dioxide. For electricity price of RM0.20 per kWh, the biodiesel consumed domestically lowers equivalent carbon dioxide emissions by about 2 million metric tons. As electricity prices exceed RM0.40 per kWh, the equivalent carbon dioxide mitigation correlates to bioelectricity production. As palm oil mills generate more bioelectricity, the bioelectricity offsets the combustion of coal and natural gas the electric companies use to produce electricity.

Figure 7 and Table 7, at last, show a minimum quantity mandate on bioelectricity generation. For the government to impose a mandate, MAPGEM needs an estimate of future electricity consumption for Malaysia. MAPGEM contains the Malaysian population forecast from DeSA (2015). Malaysians consume about 5,023.8 kWh per capita per year in 2015, while the forecasted national electricity consumption equals the Malaysian population times the per capita electricity consumed. We assume the per capita electricity consumption remains constant although it currently grows about 5% per year. The results of the quantity mandate can be dangerous because MAPGEM is a programming model that will restructure the agricultural sector to satisfy all constraints if possible, of course. MAPGEM indicates Malaysian can easily generate 15% of its electricity consumption from bioelectricity with an electricity price set to RM0.20 per kWh although the palm oil mills would earn a loss at this price.

## 5. 0 Conclusion

MAPGEM indicates the palm oil mills can supply a portion of the nation's electricity from ag wastes that stretch the nation's coal and natural gas reserves and slow greenhouse gas emissions. As mills generate more bioelectricity, they expand the ag sector and raise the production value but the price index.

The authors plan to expand MAPGEM to include bioelectricity from integrated gas combined cycle and study other renewable energies such as biodiesel, butanol, and ethanol. Furthermore, the authors plan to study carbon taxes and expand the model to study biosecurity issues.

## Acknowledgment

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Szulczyk, K. R., McCarl, B. A., & Cornforth, G. (2010). Market penetration of ethanol. *Renewable and Sustainable Energy Reviews, 14*(1), 394-403.

**Figures**

Figure 1. MAPGEM Overview

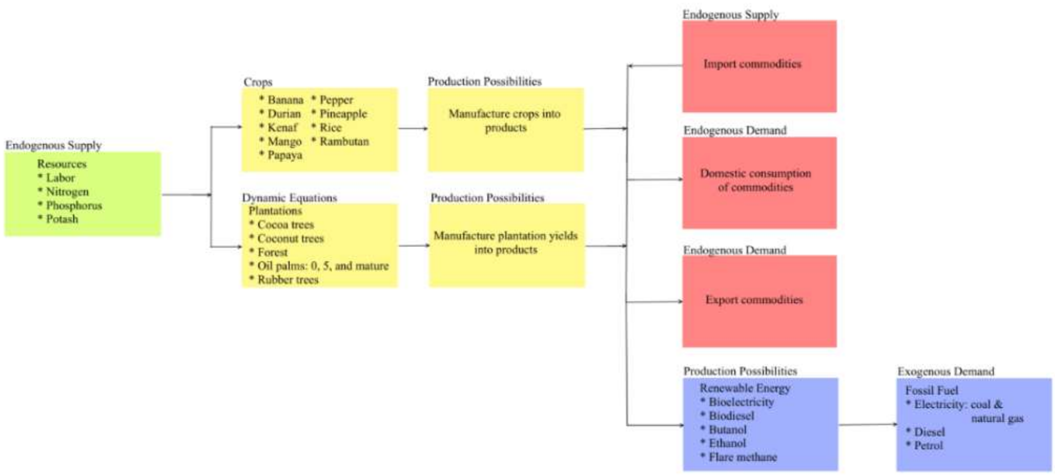
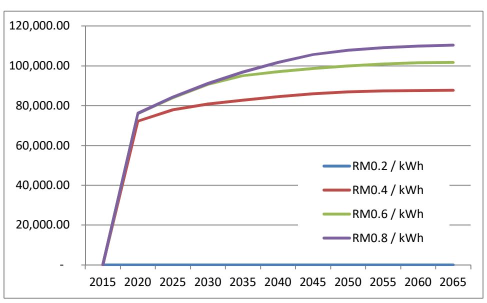
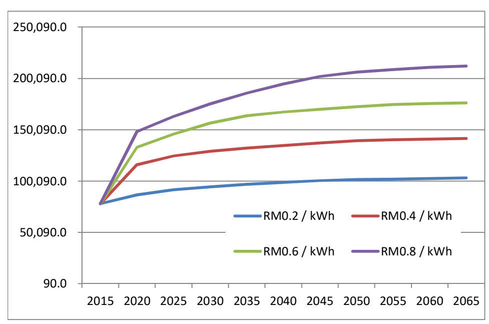



Figure 2. Production of Bioelectricity (million kWh)




Refer to Table 2 for data source.

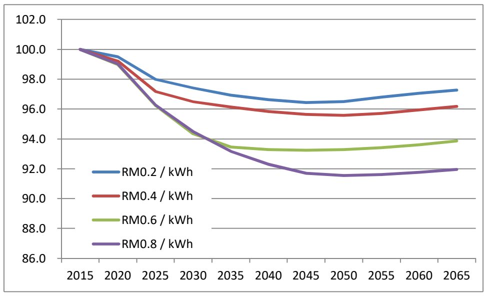
Figure 3. Production Value in 2015 Prices (millions RM)



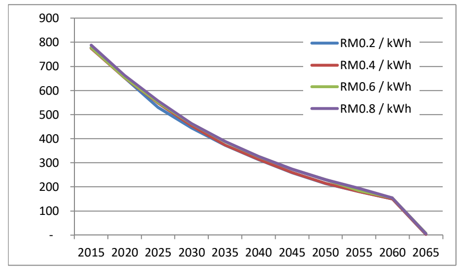

Refer to Table 3 for data source.

Table 4. Domestic Price Index

Table 5. Plantation Land Transfer (thousand hectares)

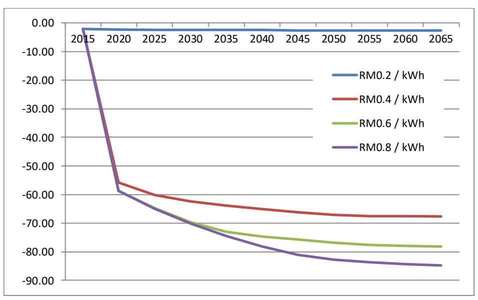



Refer to Table 4 for data source.



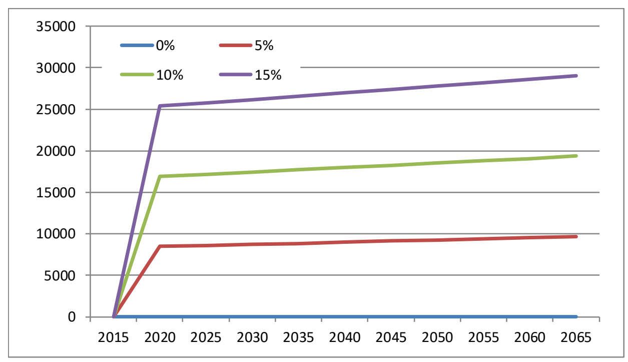

Refer to Table 5 for data source.

Table 6. Equivalent Carbon Dioxide Emissions from Renewable Energy (million metric tons)




Refer to Table 6 for data source.

Table 7. Bioelectricity Production (million kWh)




Refer to Table 7 for data source.

## Tables

Table 1. MAPGEM commodities and resources

| Source | Products |
|---|---|
| Commodities | Banana, cocoa bean, coconut, durian, kenaf, latex, 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 |
| Renewable energy | Bioelectricity, butanol, ethanol, flared methane, palm biodiesel, PFAD biodiesel, and yellow grease biodiesel |
| Agricultural and plantation wastes | Banana residues, coconut husks, empty fruit bunches (EFB), methane, palm fiber, palm fronds, palm oil mill effluent (POME), palm shell, pineapple wastes, rice husks, and rice straw |
| Resources | Land, labor, nitrogen, phosphate, and potash |

Table 2. Bioelectricity production (million kWh)

| Bioelectricity price | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 | 2060 | 2065 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RM0.2 / kWh | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| RM0.4 / kWh | 0 | 72,165.13 | 77,924.25 | 80,812.84 | 82,806.64 | 84,493.55 | 85,925.46 | 86,997.17 | 87,473.38 | 87,574.41 | 87,672.10 |
| RM0.6 / kWh | 0 | 76,046.19 | 83,999.12 | 90,701.43 | 94,988.17 | 97,102.39 | 98,625.51 | 99,903.90 | 100,978.77 | 101,510.51 | 101,667.70 |
| RM0.8 / kWh | 0 | 76,128.87 | 84,223.25 | 91,067.22 | 96,857.14 | 101,684.36 | 105,604.63 | 107,883.49 | 109,051.46 | 109,992.74 | 110,454.51 |

The data originates from MAPGEM output. Biodiesel, butanol, and ethanol prices are set to 1RM per liter while the model is solved for four different bioelectricity prices in the table. The output aggregates the bioelectricity generated at the state level from the palm oil mills.

Table 3. 2015 Production value in 2015 prices (millions RM)

| Bioelectricity price | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 | 2060 | 2065 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RM0.2 / kWh | 78,037.4 | 86,718.1 | 91,744.5 | 94,441.3 | 96,832.0 | 98,914.6 | 100,663.2 | 101,703.2 | 102,205.2 | 102,704.5 | 103,255.0 |
| RM0.4 / kWh | 78,037.4 | 116,150.6 | 124,656.2 | 129,056.6 | 132,213.0 | 134,991.3 | 137,405.7 | 139,341.2 | 140,421.7 | 140,999.0 | 141,547.8 |
| RM0.6 / kWh | 78,037.3 | 133,026.7 | 145,796.5 | 156,693.9 | 163,784.5 | 167,432.9 | 170,169.3 | 172,544.7 | 174,601.6 | 175,831.1 | 176,451.4 |
| RM0.8 / kWh | 78,037.4 | 148,348.9 | 162,948.9 | 175,329.2 | 185,887.7 | 194,749.4 | 202,045.9 | 206,399.8 | 208,793.4 | 210,821.5 | 212,027.1 |

The data comes from MAPGEM output. MAPGEM solves the model four times using the bioelectricity prices in the table. Biodiesel, butanol, and ethanol are set to RM1.00 per liter. Production equals the 2015 price times domestic consumption, plus the total value of exports, plus renewable energy sold to the electric power industry, and minus the aggregate value of imports. Production value excludes ag wastes and byproducts since they have a zero price.

Table 4. Domestic price index (%)

| Bioelectricity price | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 | 2060 | 2065 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RM0.2 / kWh | 100.0 | 99.5 | 98.0 | 97.4 | 96.9 | 96.6 | 96.4 | 96.5 | 96.8 | 97.1 | 97.3 |
| RM0.4 / kWh | 100.0 | 99.2 | 97.2 | 96.5 | 96.1 | 95.8 | 95.6 | 95.6 | 95.7 | 95.9 | 96.2 |
| RM0.6 / kWh | 100.0 | 99.0 | 96.3 | 94.4 | 93.5 | 93.3 | 93.3 | 93.3 | 93.4 | 93.6 | 93.9 |
| RM0.8 / kWh | 100.0 | 99.0 | 96.3 | 94.5 | 93.2 | 92.3 | 91.7 | 91.6 | 91.6 | 91.8 | 92.0 |

Data comes from MAPGEM by solving the model four times with the bioelectricity prices in the table. MAPGEM treats the 2015 consumption of commodities as a basket of goods. Then the price index equals the prices times the 2015 quantities divided by the base year. Price index excludes ag wastes and byproducts since they have a zero price.

Table 5. Transferring land to palm oil plantations (thousand hectares)

| Bioelectricity price | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 | 2060 | 2065 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RM0.2 / kWh | 778 | 652 | 529 | 445 | 374 | 314 | 259 | 214 | 180 | 150 | 3 |
| RM0.4 / kWh | 775 | 652 | 548 | 453 | 374 | 314 | 260 | 215 | 180 | 150 | 3 |
| RM0.6 / kWh | 778 | 654 | 550 | 463 | 387 | 325 | 273 | 230 | 185 | 153 | 6 |
| RM0.8 / kWh | 788 | 663 | 557 | 463 | 389 | 327 | 274 | 230 | 193 | 153 | 6 |

Data comes from MAPGEM by solving the model four times with the bioelectricity price in the table. The land transfer is aggregated over the states and plantation type that includes cocoa, coconut, forest, and rubber.

Table 6. Equivalent Carbon Dioxide Emissions from Renewable Energy (million metric tons)

| Diesel price per liter | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 | 2060 | 2065 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| RM0.2 / kWh | -2.06 | -2.31 | -2.39 | -2.44 | -2.49 | -2.53 | -2.57 | -2.60 | -2.62 | -2.64 | -2.67 |
| RM0.4 / kWh | -2.06 | -55.79 | -60.15 | -62.35 | -63.87 | -65.16 | -66.26 | -67.09 | -67.47 | -67.57 | -67.67 |
| RM0.6 / kWh | -2.06 | -58.67 | -64.68 | -69.74 | -72.98 | -74.59 | -75.76 | -76.75 | -77.58 | -78.00 | -78.14 |
| RM0.8 / kWh | -2.06 | -58.73 | -64.84 | -70.01 | -74.38 | -78.03 | -81.00 | -82.74 | -83.64 | -84.37 | -84.74 |

Data originates from MAPGEM by solving for the four bioelectricity prices in the table. MAGPEM converts methane and nitrous oxide into their carbon equivalents and aggregates over all states and renewable energy type. The table includes the level of carbon from biodiesel since Malaysia consumes and exports its.

Table 7. Government mandates on bioelectricity production (million kWh)

| Mandate | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 | 2055 | 2060 | 2065 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0% | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5% | 0 | 8,467 | 8,594 | 8,723 | 8,854 | 8,987 | 9,122 | 9,259 | 9,398 | 9,539 | 9,682 |
| 10% | 0 | 16,935 | 17,189 | 17,447 | 17,709 | 17,974 | 18,244 | 18,518 | 18,796 | 19,078 | 19,364 |
| 15% | 0 | 25,402 | 25,783 | 26,170 | 26,563 | 26,962 | 27,366 | 27,777 | 28,194 | 28,617 | 29,046 |

The bioelectricity is set at RM0.20 per kWh. The mandate is turned on, and MAPGEM estimates future electricity consumption from multiplying the population forecast with the 2015 per capita electricity usage. The percentage in the table is the amount the mills must supply to Malaysia.