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**A HYBRID MODEL OF SYSTEM DYNAMICS AND GENETIC
ALGORITHM TO INCREASE CRUDE PALM OIL
PRODUCTION IN MALAYSIA**



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Abstrak

Industri kelapa sawit di Malaysia sedang menghadapi perkembangan yang statik dalam pengeluaran minyak sawit mentah jika dibandingkan dengan Indonesia disebabkan tiga isu iaitu; (i) kekurangan kawasan tanaman; (ii) buruh yang terhad; dan (iii) peningkatan permintaan daripada industri biodiesel berasaskan minyak sawit. Dengan mengfokuskan isu tersebut, kajian terdahulu telah menggunakan pelbagai pendekatan. Walaubagaimanapun, penggunaan metod tanpa hibrid ini mempunyai beberapa kekurangan dan boleh ditambah baik dengan kaedah hibrid. Oleh itu, objektif kajian ini adalah untuk menentu pilihan polisi yang optimum bagi meningkatkan pengeluaran minyak sawit mentah di Malaysia. Dalam kajian ini, sebuah model hibrid sistem dinamik dan algoritma genetik telah dibangunkan untuk menentu polisi yang optimum bagi meningkatkan pengeluaran minyak sawit mentah di Malaysia. Lima pembolehubah polisi iaitu kadar penggunaan mesin, purata penanaman semula, mandat biodiesel di sektor pengangkutan, industri, dan 4 sektor yang relevan bagi mengenalpasti nilai polisi yang optimum. Lima pembolehubah polisi ini diuji dalam tiga scenario: tahun 2017, tahun 2020, dan berfasa sehingga tahun 2050. Daripada semua senario, optimisasi secara berfasa didapati paling berkesan dalam menghasilkan nilai pembolehubah polisi yang sesuai untuk mendapatkan pengeluaran minyak sawit mentah yang terbaik pada tahun 2050 setakat 20 larian populasi GA. Hybrid SD-GA melalui optimisasi secara berfasa mampu untuk mencadangkan polisi yang meyakinkan untuk dilaksana bagi mengelakkan kejutan yang tidak diingini kepada industri. Tambahan lagi, model hibrid ini juga berupaya untuk mengenalpasti pembolehubah polisi yang berkaitan dengan fungsi objektif pada sesuatu tempoh masa yang spesifik. Daripada perspektif pengurusan, kajian ini boleh membantu pihak pemegang taruh dalam industri minyak sawit ke arah pembuatan keputusan pelaburan yang lebih baik.

Kata kunci: Pengeluaran minyak sawit mentah, Sistem dinamik, Algoritma genetik, model hibrid SD-GA, polisi minyak sawit mentah

Abstract

Palm oil industry in Malaysia is facing a stagnant growth in terms of crude palm oil (CPO) production as compared to Indonesia due to three issues namely (i) the scarcity of plantation area, (ii) labour shortage, and (iii) the rising demand from palm-based biodiesel industry. Focusing on these issues, previous studies have been adopted various approaches. However, these non-hybridized methods have some shortcomings and can be improved by hybridization method. Hence, the objective of this research is to determine the optimal policy options to increase CPO production in Malaysia. In this research, a hybrid model of system dynamics (SD) and genetic algorithm (GA) was developed to determine the optimal policy in increasing the CPO production in Malaysia. Five policy variables namely mechanization adoption rate, average replanting, biodiesel mandates in transportation, industrial and 4 other relevant sectors were examined to determine optimal policy values. These five policy variables were tested in three scenarios: year 2017, year 2020, and in phases until 2050. From all the scenarios, the phase optimization emerged as the most effective in producing suitable policy variable values in order to obtain the best possible value of CPO production in year 2050 up to 20 GA population runs. The hybrid of SD-GA through phase optimization process is capable to recommend policies that are plausible to be implemented to avoid unwarranted shock to the industry. Furthermore, the hybrid model provides the ability of identifying the policy variables related to the objective function at any specific time line. From the managerial perspectives, this research helps the stakeholders in palm oil industry towards making a better future investment decision.

Keywords: Crude palm oil production, System dynamics, Genetic algorithm, SD-GA hybrid model, CPO policy

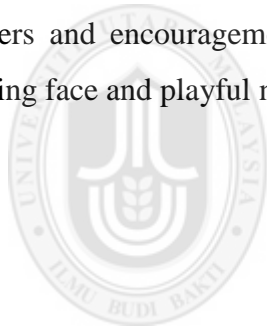
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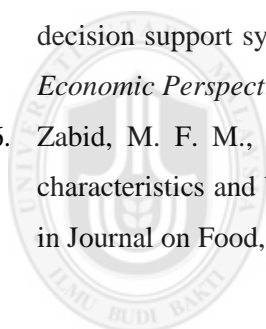
2SLS	Two Stage Least Squares
ABM	Agent-Based Modeling
AIDS	Acquired Immune Deficiency Syndrome
ARDL	Auto Regressive Distribution Lag
ARIMA	Auto Regressive Moving Average
CPO	Crude Palm Oil
DES	Discrete Event Simulation
DO	Dynamic Optimization
DSS	Decision Support System
EPP	Entry Point Project
ETP	Economic Transformation Program
GA	Genetic Algorithm
GHG	Green-House Gasses
GNI	Gross National Income
ISIS	Information Society Integrated System
MAPA	Malayan Agricultural Producers Association
MOO	Multiple Objective Optimization
MPOB	Malaysian Palm Oil Board
MSPO	Malaysian Sustainable Palm Oil
MyGAP	Malaysian Good Agricultural Practices
N2SLS	Nonlinear Two Stage Least Squares
NKEA	National Key Economic Area
OLS	Ordinary Least Squares
PPO	Processed Palm Oil
PRN	Partial Recurrent Network
RNN	Recurrent Neural Network
SCOR	Supply Chain Operational Reference
SD	System Dynamics
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution

VB Visual Basics
VensimDLL Vensim Direct Link Library



Publications

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CHAPTER ONE

INTRODUCTION

Vegetable oils have been an important commodity in the world oils and fats market. In the recent decade, it has become the main substitutes of animal fats as the source of cooking oils and fats. Among the seven highly traded vegetable oil in the world market, palm oil has been significantly increased in terms of its production and consumption. This is hugely attributing to its economic viability in oil palm plantation and palm oil production vis-à-vis other vegetable oil. Currently, the world largest producer of palm oil is Indonesia followed by Malaysia, with the combination of these two countries the total production of palm oil contributes approximately eighty percent of the world palm oil production (MPOB, 2016; GAPKI, 2016).

1.1 Palm Oil Industry in Malaysia at a Glance

The important role of palm oil as one of the Malaysia's main economic contributor cannot be denied, as this industry has been studied from many perspectives. For instance in the general economic perspective (Shamsudin, Mohamed, & Arshad, 1988; Shamsudin, Arshad, Mohammad, & Rahman, 1995; Mohammad, Mohd Fauzi, & Ramli, 1999); palm-based biodiesel industry (Yahaya, Sabri, & Kennedy, 2006; Shri Dewi, Ali, & Alias, 2014; Azadeh, Arani, & Dashti, 2014); production planning (Tan & Fong, 1998; Nwawe, Akintola, Ikpi, & Rahji, 2008; Banitalebi, Aziz, Aziz, & Nasir, 2016); and environment (Diban, Aziz, Foo, Jia, Li, & Tan, 2016). Palm oil also is an important economic stimulus as there are many affiliates industries such as food, cosmetics and alternative fuel that also contribute to the economic growth in Malaysia. In 2016, a total of RM41.44 billion of export value was contributed by palm oil industry which accounts for 5.3 percent of total Malaysia's export value (MATRADE, 2017).

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APPENDIX

APPENDIX A: Palm Oil Supply Demand Sub-Model Equations

Average OER= 0.22

Units: Dmnl

Base CPO export demand growth= 3

Units: 1/Year

Base CPO import=

$60000 + \text{RAMP}(200000, 0, 3) + \text{RAMP}(80000, 3, 5) + \text{RAMP}(500, 5, 8) + \text{RAMP}(400000, 8, 11) + \text{RAMP}(5000, 11, 70)$

Units: Tonne/Year

Base PPO export demand growth= 0.201

Units: 1/Year

Base PPO local demand growth= 0.155

Units: 1/Year

Biodiesel production= INTEG (Biodiesel production rate, 0)

Units: Tonne

CPO demand for biodiesel= Biodiesel production

Units: Tonne

CPO demand for PPO=Total PPO demand

Units: Tonne

CPO excess stock=Total CPO supply-Total CPO demand

Units: Tonne

CPO export demand= INTEG (CPO export demand change, 400000)

Units: Tonne

CPO export demand change=

$\text{CPO export demand} * \text{Base CPO export demand growth} * \text{Factor affecting CPO export demand}$

Units: Tonne/Year

CPO export tax=

$\text{STEP}(\text{Lookup for CPO tax structure}(\text{CPO price}), 13)$

Units: Dmnl

CPO import= INTEG (CPO import change, 46000)

Units: Tonne

CPO import change= Base CPO import*Effect of SB price on CPO import-CPO import

Units: Tonne/Year

CPO price= INTEG (CPO price change, 990)
Units: RM

CPO price change= Indicated CPO price/Time for CPO price adjustment
Units: RM/Year

CPO price influence on CPO export demand=
Lookup for effect of CPO price on CPO export demand (Relative CPO price on export demand)
Units: Dmnl

CPO production= INTEG (CPO production rate, 1e+007)
Units: Tonne

CPO production rate=
(Average OER*Total FFB yield-CPO production)/Time to adjust CPO production
Units: Tonne/Year

CPO supply demand ratio= Total CPO supply/Total CPO demand
Units: Dmnl

Effect of CPO export tax on demand=
1+STEP(-1+Lookup for effect of CPO export tax on CPO export(CPO export tax /Reference CPO export tax),13)
Units: Dmnl

Effect of CPO supply demand ratio on CPO price=
Lookup for effect of CPO SD on CPO price(Relative SD ratio)
Units: RM

Effect of SB price on CPO import=
(Soybean oil price/Reference soybean oil price)^Sensitivity of soybean oil price on CPO import
Units: Dmnl

Factor affecting CPO export demand=
CPO price influence on CPO export demand*Soybean oil price influence on CPO export demand*Effect of CPO export tax on demand
Units: Dmnl

Factor affecting PPO export demand=
PPO price influence on PPO export demand*Soybean oil price influence on PPO export
Units: Dmnl

Factor affecting PPO local demand=
PPO price influence on PPO local demand*SBO price influence on PPO local demand
Units: Dmnl

Historical soybean oil prices= Lookup for historical SBO prices (Time)
Units: USD/Tonne

Indicated CPO price= Effect of CPO supply demand ratio on CPO price

Units: RM

Initial CPO price references on CPO export demand= 3500

Units: RM

Initial PPO prices on PPO export demand= 3500

Units: RM

Initial reference CPO SD ratio= 1.5

Units: Dmnl

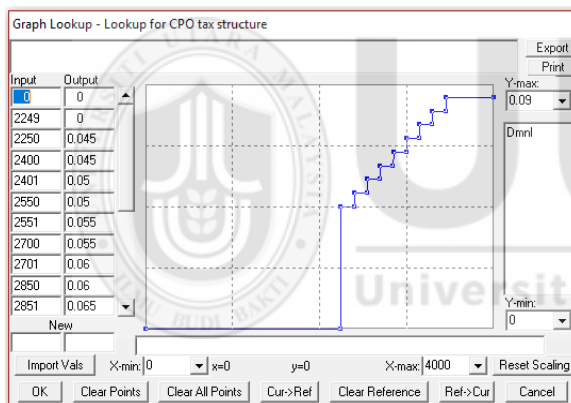
Initial reference PPO price on PPO local demand= 3500

Units: Dmnl

Lookup for CPO tax structure(

$[(0,0)-(4000,0.09)],(0,0),(2249,0),(2250,0.045),(2400,0.045),(2401,0.05),(2550,0.05),(2551,0.055),(2700,0.055),(2701,0.06),(2850,0.06),(2851,0.065),(3000,0.065),(3001,0.07),(3150,0.07),(3151,0.075),(3300,0.075),(3301,0.08),(3450,0.08),(3451,0.085),(4000,0.085))$

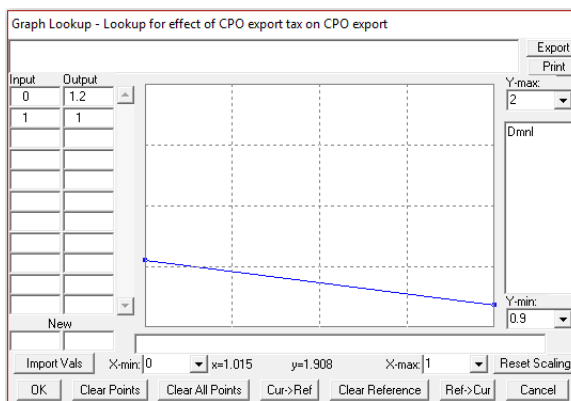
Units: Dmnl



Lookup for effect of CPO export tax on CPO export(

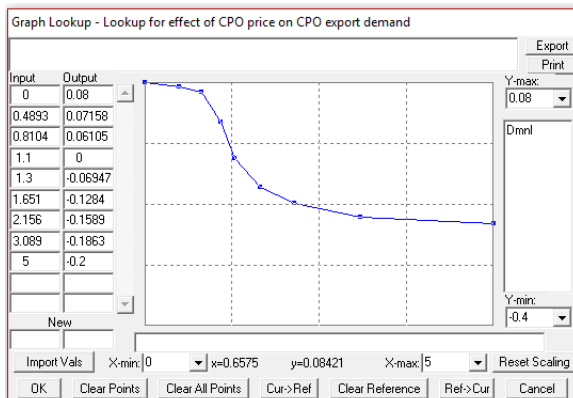
$[(0,0.9)-(1,2)],(0,1.05),(1,1)$

Units: Dmnl



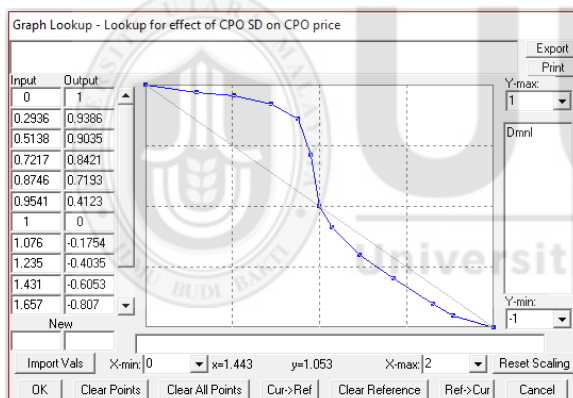
Lookup for effect of CPO price on CPO export demand(

$[(0,-0.4)-(5,0.08)],(0,0.08),(0.489297,0.0715789),(0.810398,0.0610526),(1.1,0),$
 $(1.29969,-0.0694737),(1.65138,-0.128421),(2.15596,-0.1589),(3.08869,-0.1863),(5,-0.2)$
 Units: Dmnl



Lookup for effect of CPO SD on CPO price(

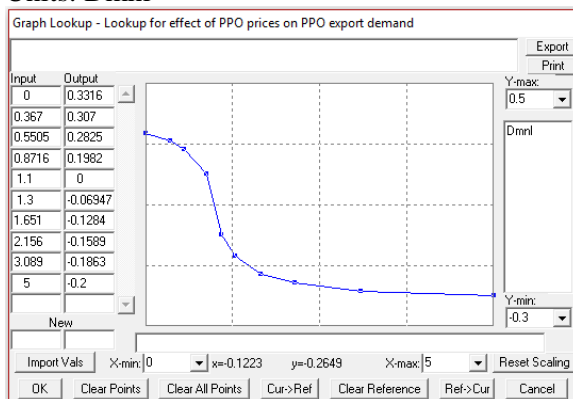
$[(0,-1)-(2,1),(0,1),(1,0),(2,-1)],(0,1),(0.293578,0.938596),(0.513761,0.903509),$
 $(0.721713,0.842105),(0.874618,0.719298),(0.954128,0.412281),(1,0),(1.07645,0.175439),$
 $(1.23547,-0.403509),(1.43119,-0.605263),(1.65749,-0.807018),(1.7737,-0.903509),(2,-1)$
 Units: Dmnl



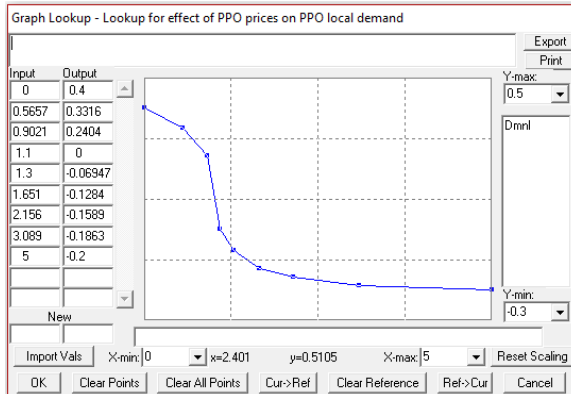
Lookup for effect of PPO prices on PPO export demand(

$[(0,-0.3)-(5,0.5)],(0,0.331579),(0.366972,0.307018),(0.550459,0.282456),(0.87156$
 $,0.198246),(1.1,0),(1.29969,-0.0694737),(1.65138,-0.128421),(2.15596,-0.1589),(3.08869,$
 $0.1863),(5,-0.2)$

Units: Dmnl



Lookup for effect of PPO prices on PPO local demand(
 [(0,-0.3)-(5,0.5)],(0,0.4),(0.565749,0.331579),(0.902141,0.240351),(1.1,0)
 ,(1.29969,-0.0694737),(1.65138,-0.128421),(2.15596,-0.1589),(3.08869,-0.1863),(5,-0.2))
 Units: Dmnl



PPO export demand= INTEG (PPO export demand change, 9e+006)
 Units: Tonne

PPO export demand change=
 Factor affecting PPO export demand*Base PPO export demand growth*PPO export demand
 Units: Tonne/Year

PPO local demand= INTEG (PPO local demand change, 1.2e+006)
 Units: Tonne

PPO local demand change=
 Factor affecting PPO local demand*Base PPO local demand growth*PPO local demand
 Units: Tonne/Year

PPO price= 1.03*CPO price
 Units: RM

PPO price influence on PPO export demand=
 Lookup for effect of PPO prices on PPO export demand (Relative PPO prices on export demand)
 Units: Dmnl

PPO price influence on PPO local demand=
 Lookup for effect of PPO prices on PPO local demand (Relative PPO prices on local demand)
 Units: Dmnl

Reference CPO export tax= 0.045
 Units: Dmnl

Reference CPO price on CPO export demand=

SMOOTH3I(CPO price,Time for CPO price references on CPO export demand,Initial CPO price references on CPO export demand)
Units: RM

Reference CPO SD ratio=
SMOOTH3I(CPO supply demand ratio, Time to perceived CPO SD ratio, Initial reference CPO SD ratio)
Units: Dmnl

Reference PPO price on PPO export demand=
SMOOTH3I(PPO price,Time for PPO price references on PPO export demand,Initial PPO prices on PPO export demand)
Units: RM

Reference PPO price on PPO local demand=
SMOOTH3I(PPO price,Time for PPO price references on PPO local demand,Initial reference PPO price on PPO local demand)
Units: RM

Reference soybean oil price= 980
Units: USD/Tonne

Relative CPO price on export demand=
CPO price/Reference CPO price on CPO export demand
Units: Dmnl

Relative PPO prices on export demand=
PPO price/Reference PPO price on PPO export demand
Units: Dmnl

Relative PPO prices on local demand=
PPO price/Reference PPO price on PPO local demand
Units: Dmnl

Relative SD ratio=
CPO supply demand ratio/Reference CPO SD ratio
Units: Dmnl

SBO price influence on PPO local demand=
(Soybean oil price/Reference soybean oil price)^Sensitivity of SBO prices on PPO local demand
Units: Dmnl

Sensitivity of SBO prices on PPO local demand= 0.479
Units: Dmnl

Sensitivity of soybean oil price on CPO import= 0.1
Units: Dmnl

Sensitivity of soybean oil price on PPO export demand= 0.004
Units: Dmnl

Sensitivity of soybean oil prices on CPO export demand= 0.9

Units: Dmnl

0.001

Soybean oil price= DELAY3(Historical soybean oil prices, 3)

Units: USD/Tonne

Soybean oil price influence on CPO export demand=

(Soybean oil price/Reference soybean oil price)^Sensitivity of soybean oil prices on CPO export demand

Units: Dmnl

Soybean oil price influence on PPO export=

(Soybean oil price/Reference soybean oil price)^Sensitivity of soybean oil price on PPO export demand

Units: Dmnl

Time for CPO price adjustment= 2

Units: Year

Time for CPO price references on CPO export demand= 5

Units: Year

Time for PPO price references on PPO export demand= 5

Units: Year

Time for PPO price references on PPO local demand= 5

Units: Year

Time to adjust CPO production= 1

Units: Year

Time to perceived CPO SD ratio= 5

Units: Year

Total CPO demand= CPO demand for PPO+CPO export demand + CPO demand for biodiesel

Units: Tonne

Total CPO supply= CPO production + CPO import

Units: Tonne

Total FFB yield=

Effect of labour on FFB yield*SMOOTH (Effect of adverse weather on FFB yield 4)
*(Mature area yield + Ageing area yield)

Units: Tonne

Total PPO demand= PPO export demand + PPO local demand

Units: Tonne

APPENDIX B: Oil Palm Plantation Sub-Model Equations

Ageing area= INTEG (Ageing rate-Cutting rate, 1e+006)

Units: Hectare

Ageing area yield= Ageing area*Avg yield per ha for ageing area

Units: Tonne

Ageing period= 20

Units: Year

Ageing rate=

Fraction of ageing rate + (Initial mature area/Ageing period)*PULSE(0,20)

Units: Hectare/Year

Avg new planting= 150000

Units: Hectare

Avg replanting= 50000

Units: Hectare

Avg yield per ha for ageing area= 19

Units: Tonne/Hectare

Avg yield per ha for mature area= 25

Units: Tonne/Hectare

CPO price effect on replanting=

Lookup for CPO price effect on replanting (Relative CPO price on replanting)

Units: Dmnl

Cutting rate= MIN(Ageing area, Replanting)/Time for cutting

Units: Hectare/Year

Effect of adverse weather on FFB yield=

$1+(-0.1*\text{PULSE}(0, 1)) + (-0.1*\text{PULSE}(4, 1)) + (-0.1*\text{PULSE}(8, 1)) + (-0.1*\text{PULSE}(12, 1)) + (-0.1*\text{PULSE}(16, 1)) + (-0.1*\text{PULSE}(20, 1)) + (-0.1*\text{PULSE}(24, 1)) + (-0.1*\text{PULSE}(28, 1)) + (-0.1*\text{PULSE}(32, 1)) + (-0.1*\text{PULSE}(36, 1)) + (-0.1*\text{PULSE}(40, 1)) + (-0.1*\text{PULSE}(44, 1)) + (-0.1*\text{PULSE}(48, 1)) + (-0.1*\text{PULSE}(52, 1)) + (-0.1*\text{PULSE}(56, 1)) + (-0.1*\text{PULSE}(60, 1)) + (-0.1*\text{PULSE}(64, 1))$

Units: Dmnl

Effect of labour on FFB yield=

Lookup for effect of labour on FFB yield(Relative labour land ratio)

Units: Dmnl

Effect of land availability on expansion plan=

Lookup for effect of land availability on expansion plan(Ratio of potential land for oil palm plantation)

Units: Dmnl

FFB yield per ha= Total FFB yield/Total plantation area

Units: Tonne/Hectare

Fraction of ageing rate= DELAY FIXED(Maturity rate, Ageing period , 0)

Units: Hectare/Year

Fraction of maturity rate= DELAY FIXED(Planting rate, Maturity period , 0)

Units: Hectare/Year

Initial CPO price references on replanting=

5000

Units: Tonne

Initial mature area= 2e+006

Units: Hectare

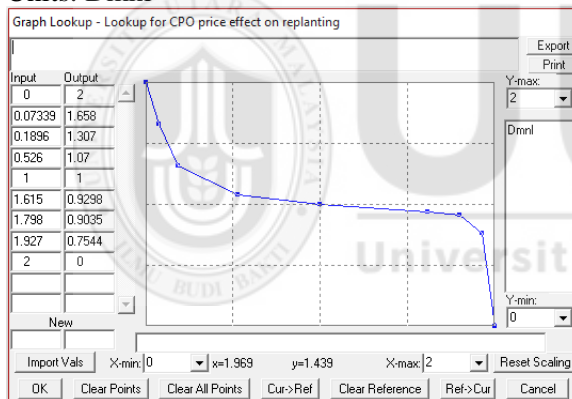
Initial premature area= 300000

Units: Hectare

Lookup for CPO price effect on replanting (

$[(0,0)-(2,2)],(0,2),(0.0733945,1.65789),(0.189602,1.30702),(0.525994,1.07018),$
 $(1,1),(1.61468,0.929825),(1.79817,0.903509),(1.92661,0.754386),(2,0)$

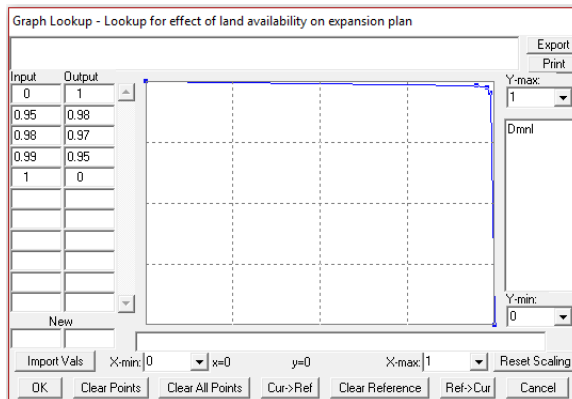
Units: Dmnl



Lookup for effect of land availability on expansion plan(

$[(0,0)-(1,1)],(0,1),(0.95,0.98),(0.98,0.97),(0.99,0.95),(1,0)$

Units: Dmnl



Mature area= INTEG (Maturity rate-Ageing rate, Initial mature area)
Units: Hectare

Mature area yield= Mature area*Avg yield per ha for mature area
Units: Tonne

Maturity period=3
Units: Year

Maturity rate=
Fraction of maturity rate+(Initial premature area/Maturity period)*PULSE(0,3)
Units: Hectare/Year

Max land available= 6e+006
Units: Hectare

Motivation to replant= CPO price effect on replanting
Units: Dmnl

New planting=
MIN(Effect of land availability on expansion plan*Avg new planting, Vacant land)
Units: Hectare

Planting rate= (New planting + Replanting)/Time for planting
Units: Hectare/Year

Premature area= INTEG (Planting rate-Maturity rate, Initial premature area)
Units: Hectare

Ratio of potential land for oil palm plantation= Total plantation area/Max land available
Units: Dmnl

Reference CPO price on replanting=
SMOOTH3I(CPO price, Time for CPO price references on replanting, Initial CPO price references on replanting)
Units: RM

Relative CPO price on replanting= CPO price/Reference CPO price on replanting
Units: Dmnl

Replanting= MIN(Motivation to replant*Replanting rate, Ageing area)
Units: Hectare

Replanting rate=
50000+STEP(Avg replanting-50000, Year of replanting change-2000)
Units: Hectare

Time for CPO price references on replanting= 5
Units: Year

Time for cutting= 1
Units: Year

Time for planting= 1
Units: Year

Total FFB yield=
Effect of labour on FFB yield*SMOOTH(Effect of adverse weather on FFB yield,
4)*(Mature area yield + Ageing area yield)
Units: Tonne

Total plantation area= Premature area + Mature area + Ageing area
Units: Hectare

Total productive area= Mature area + Ageing area
Units: Hectare

Vacant land= MAX(Max land available-Total plantation area,0)
Units: Hectare

Year of replanting change= 2017
Units: Year



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APPENDIX C: Palm-Based Biodiesel Sub-Model Equations

Biodiesel demand in industrial sector=

$$\text{Total diesel use in industrial sector} * \text{Biodiesel mandate for industrial sector} * \text{STEP}(1,16)$$

Units: Tonne

Biodiesel demand in other sector=

$$\text{Total diesel use in other sector} * \text{Biodiesel mandate for other sector}$$

Units: Tonne

Biodiesel demand in transport sector=

$$\text{Biodiesel mandate for transport sector} * \text{Total diesel use on road}$$

Units: Tonne

Biodiesel export= 100000

Units: Tonne

Biodiesel mandate for industrial sector=

$$\text{STEP}(0.07,16) + \text{STEP}(\text{Current biodiesel mandate for industrial sector} - 0.07, \text{Year of biodiesel mandate for industrial sector implementation} - 2000)$$

Units: Dmnl

Biodiesel mandate for other sector=

$$\text{STEP}(\text{Current biodiesel mandate for other sector}, \text{Year of biodiesel mandate for other sector implementation} - 2000)$$

Units: Dmnl

Biodiesel mandate for transport sector=

$$\text{STEP}(0.05,11) + \text{STEP}(0.07 - 0.05,14) + \text{STEP}(0.1 - 0.07,16) + \text{STEP}(\text{Current biodiesel mandate for transport sector} - 0.1, \text{Year of biodiesel mandate for transport sector implementation} - 2000)$$

Units: Dmnl

Biodiesel production= INTEG (Biodiesel production rate, 0)

Units: Tonne

Biodiesel production rate=

$$(\text{Total biodiesel demand} - \text{Biodiesel production}) / \text{Time to adjust biodiesel production}$$

Units: Tonne/Year

Current biodiesel mandate for industrial sector= 0.07

Units: Dmnl

Current biodiesel mandate for other sector= 0

Units: Dmnl

Current biodiesel mandate for transport sector= 0.39

Units: Dmnl

Time to adjust biodiesel production= 1

Units: Year

Total biodiesel demand=

$STEP(1, 0) + \text{Biodiesel demand in transport sector} + \text{Biodiesel demand in industrial sector} + \text{Biodiesel export} + \text{Biodiesel demand in other sector}$

Units: Tonne

TOTAL diesel consumption in all sector=

$\text{Total diesel use on road} + \text{Total diesel use in agriculture sector} + \text{Total diesel use in construction and mining sector} + \text{Total diesel use in industrial sector} + \text{Total diesel use in shipping and rail sector}$

Units: Tonne

Total diesel use in agriculture sector= $26803 * \text{Time} + 550316$

Units: Tonne

Total diesel use in construction and mining sector= $10309 * \text{Time} + 211659$

Units: Tonne

Total diesel use in industrial sector= $8247.2 * \text{Time} + 169327$

Units: Tonne

Total diesel use in other sector=

$\text{Total diesel use in agriculture sector} + \text{Total diesel use in construction and mining sector} + \text{Total diesel use in shipping and rail sector}$

Units: Tonne

Total diesel use in shipping and rail sector= $26803 * \text{Time} + 550316$

Units: Tonne

Total diesel use on road= $134016 * \text{Time} + 3e+006$

Units: Tonne

Year of biodiesel mandate for industrial sector implementation= 2020

Units: Year

Year of biodiesel mandate for other sector implementation= 2020

Units: Year

Year of biodiesel mandate for transport sector implementation= 2020

Units: Year

APPENDIX D: Labour Sub-Model Equations

Actual labour land ratio= Labour stock/Total plantation area

Units: Labour/Hectare

Attractiveness of Indonesia palm oil industry=

$$1 + (0.3 * \text{Relative Indonesia palm oil growth} + 0.7 * \text{Relative wage rate})$$

Units: Dmnl

Contract duration= 5

Units: Year

Desired labour=

$$\text{Total plantation area} * \text{Optimal labour land ratio}$$

Units: Labour

Effect of labour on FFB yield=

$$\text{Lookup for effect of labour on FFB yield (Relative labour land ratio)}$$

Units: Dmnl

Effect of mechanization on labour=

$$0.2 + \text{STEP}(\text{Mechanization adoption rate} - 0.2, \text{Year of mechanization use change} - 2000)$$

Units: Dmnl

Factor affecting labour off rate= Attractiveness of Indonesia palm oil industry

Units: Dmnl

Fraction of labour taking= 0.25

Units: 1/Year

Gap of labour= Desired labour-Labour stock

Units: Labour

Indonesia palm oil industry growth= 3.4

Units: Dmnl

Indonesia wage= INTEG (Indonesia wage change, 300)

Units: RM

Indonesia wage change= Indonesia wage*Indonesia wage rate growth

Units: RM/Year

Indonesia wage rate growth= 0.04

Units: 1/Year

Labour off rate=

$$\text{Factor affecting labour off rate} * \text{Labour stock} / \text{Contract duration} * \text{Year of contract duration change}$$

Units: Labour/Year

Labour stock= INTEG (Labour taking rate-Labour off rate, 250000)

Units: Labour

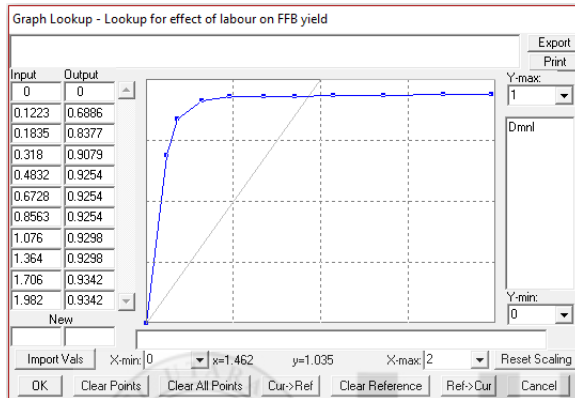
Labour taking rate= Fraction of labour taking*Gap of labour

Units: Labour/Year

Lookup for effect of labour on FFB yield (

$[(0,0)-(2,1),(0,0),(1,1),(2,1)],(0,0),(0.122324,0.688596),(0.183486,0.837719),$
 $(0.318043,0.907895),(0.48318,0.925439),(0.672783,0.925439),(0.856269,0.925439)$
 $),(1.07645,0.929825),(1.36391,0.929825),(1.70642,0.934211),(1.98165,0.934211))$

Units: Dmnl



Malaysia palm oil industry growth= 0.8

Units: Dmnl

Malaysia wage= INTEG (Malaysia wage change, 600)

Units: RM

Malaysia wage change= Malaysia wage*Malaysia wage rate growth

Units: RM/Year

Malaysia wage rate growth= 0.028

Units: 1/Year

Mechanization adoption rate= 0.2

Units: Dmnl

Optimal labour land ratio= 0.167

Units: Labour/Hectare

Relative Indonesia palm oil growth=

$\text{Indonesia palm oil industry growth} / \text{Malaysia palm oil industry growth}$

Units: Dmnl

Relative labour land ratio=

$\text{Actual labour land ratio} / (\text{Optimal labour land ratio} / (1 + \text{Effect of mechanization on labour}))$

Units: Dmnl

Relative wage rate= Indonesia wage/Malaysia wage
Units: Dmnl

Total plantation area= Premature area + Mature area + Ageing area
Units: Hectare

Year of contract duration change= 1
Units: Dmnl

Year of mechanization use change=2017
Units: Year

