NUMERICAL STUDY OF PRODUCTION, LOGISTICS AND FACILITY LOCATION PLANNING FOR OIL PALM IN BIO-DIESEL PRODUCTION FOR THAILAND

Artchapong Hassametto
Preerawadee Chaiboontun
Chattraporn Prajuabwan
Laphatrada Khammuang
Aussadavut Dumrongsiri†

School of Management Technology,
Sirindhorn International Institute of Technology, Thammasat University,
Pathum Thani, 12000, THAILAND
Email: aussadavut@gmail.com

Abstract

This research studies the planning of production of fresh fruit brunch of oil palm for biodiesel production in Thailand. The research also considers the logistics planning and capacity of oil palm mill and location of the mills to minimize the total cost. Due to the increasing demand of biodiesel as a result of Thai government renewable and alternative energy policy, the supply of palm oil and the processing capacity of the mills are not enough. Because the problems are complex because all aspects of production, logistics and capacity planning must jointly considered. Also, because of the nature of oil palm tree that has varying production rate (depending the ages of the tree), it is difficult to do the production plan precisely. We developed a mathematical model to help planning of oil palm production, transportation and oil palm mill capacity and locations so that the demand can be satisfied with minimal production, logistics and facility costs. Our model allows the production rate and net profit to vary over the life cycle of oil palm tree. To provide the guideline for Thailand, we collected secondary data from various sources to plug into the model. The model is solved using IBM ILOG CPLEX version 12.1. The result shows that the model works well to closely match supply with the increasing demand. The model also suggests the required planting areas to be prepared and the additional capacity to be installed for all zones of Thailand.

Keywords: Bio-diesel, Oil palm, Production planning, Mathematical model, Optimization

1. INTRODUCTION

Energy problem is one of the most important issues seeming endless and continually affects human being directly. Recently, crude oil price is increasing every year. Oil palm is one of crops providing the highest oil yields. Thai government tries to promote bio-energy projects including using palm oil to produce biodiesel as the alternative energy for diesel petroleum. Thailand has limited fossil resources and has to import a large amount of fuel to

† Corresponding author

fulfill rapidly increasing diesel demand. The diesel demand is 9,928 million liters in 1990 and increase to 18,273 million liters in 2004 or increasing with average rate of 4.5% per years. Palm oil is main raw material for bio-diesel production in Thailand due it has highest crop yield compared to other plants. Thai government set up policy to promote the production of palm oil based biodiesel as a renewable source of energy for the transport sector according to the 10 years renewable and alternative energy development 10 year plan (2012–2021). According to the plan, the demand of B100 (pure-form of biodiesel) is expected to be 4.5 million liters per day, more than threefold of 2010 demand which was at 1.35 million liters per day.

However, even though the demand is increasing, there are limited planting areas to meet the demand. Also, it is challenging to meet the increasing demand at the minimal total cost by efficiently planning the production and logistics of fresh fruit brunches (FFB) of oil palm and selecting locations of processing plants to support the production. Our research aims to solve such the problem. We developed a mathematical model to plan the production of oil palm by taking into account of production rate varying over the plant life cycle. The model also take into account the cost to transport FFB to the nearest processing plants at the while meeting the processing plant capacity. If the capacity of processing plant is not enough, the model suggests the amount and location of new capacity to be installed. To make the model useful, we gathered the secondary data of information to use in the model so that we can provide a roadmap for Thailand. Private companies trying to satisfy demand from her planation can also use the model.

2. MATHEMATICAL MODEL

We consider a decision maker such as, company or a government, who own *j* pieces of land. The size of land *j* is N_j. Each piece of land can be used to plant oil palm independently. But all the trees in the same piece of land have the same schedule. That is, they are planted initially at the same time and they are replaced by the new trees at the same time. If the oil palm trees in a piece of land are planted in period *b* and are replaced by the new set of trees in period *e,* during the period $t \in \{b, b+1, ..., e\}$, the production rate of fresh fruit bunches (FFB) (tons) per unit of land is $p_{b,e,t}$. At the same time, the total profit per land unit, excluding the transportation cost and facility cost, from planting the oil palm trees in period *b* and replacing them in period *e* is $\pi_{b,e}$. In each period, the total production of FFB from all areas must equal to or exceed the total demand of FFB, D_t. All FFB produced at land j must be transported to FFB processing plants to produce the crude palm oil (CPO). There is a transportation cost to transport FFB from the planting area to the processing plant. It costs *c* to transport one ton of FFB for one kilometer. The distance in kilometers from land *j* to plant *k* is $d_{j,k}$. We assume that the existing capacity of production facility at plant *k* is $C_{k,0}$. To build the additional capacity of palm oil production facility at plant *k*, it costs f_k per ton of FFB. We also assume that if the land *j* is assigned to grow a set of the trees from period *b* to *e*, the land *j* cannot be used to grow other sets of trees in any periods from *b* to *e*. The discussed parameters are summarized below.

Parameters:

$N_j \quad = size\ of\ land\ j$

$c \quad = transportation\ cost\ to\ transport\ one\ ton\ of\ FFB\ for\ one\ kilometer$

$d_{jk} \quad = transportation\ distance\ (km)\ from\ land\ j\ to\ plant\ k$

$D_t \quad = demand\ of\ FFB\ in\ period\ t$

$\pi_{b,e} \quad = total\ profit\ per\ unit\ of\ land\ excluding\ transportation\ cost\ and\ facility\ cost$
$\quad during\ periods\ from\ b\ to\ e$

$p_{b,e,t} = production\ rate\ (tons)\ of\ FFB\ per\ unit\ of\ land\ in\ period\ t\ given\ that\ the$
$\quad oil\ palm\ trees\ were\ planted\ in\ period\ b\ and\ replaced\ in\ period\ e.$

$f_k \quad = facility\ cost\ to\ increase\ one\ ton\ of\ FFB\ processing\ capacity\ at\ location\ k$

$C_{k,0} \quad = existing\ capacity\ of\ FFB\ processing\ plant\ at\ location\ k$

$M \quad = very\ large\ number$

$T \quad = total\ number\ of\ planning\ periods$

$J \quad = total\ number\ of\ pieces\ of\ land$

$K \quad = total\ number\ of\ plant\ locations$

The decision maker has to decide the following decision variables.

Decision Variables:

$x_{j,k,t} = quantity\ of\ FFB\ (tons)\ transported\ from\ land\ j\ to\ plant\ k\ in\ period\ t$

$C_{k,t} \quad = number\ of\ plant\ capacity\ (tons)\ added\ at\ plant\ k\ in\ period\ t$

$z_{b,e,j} = 1\ if\ the\ land\ j\ is\ assigned\ to\ plant\ oil\ palm\ trees\ for\ all\ periods\ from\ b\ to\ e$

$\quad = 0\ otherwise$

The mathematical model to make the optimal decisions on the production planning, the logistics planning and facility planning is as follows.

$$Maximize \sum_{j=1}^{J}\sum_{b=1}^{T}\sum_{e\geq b}^{T} N_j \pi_{b,e} z_{b,e,j} - \sum_{t=1}^{T}\sum_{j=1}^{J}\sum_{k=1}^{K} N_j cd_{jk} x_{jkt} - \sum_{t=1}^{T}\sum_{k=1}^{K} f_k C_{k,t} \quad (1)$$

Subject to

$$\sum_{j=1}^{J}\sum_{b=1}^{T}\sum_{e\geq b}^{T} N_j z_{b,e,j} p_{b,e,t} \geq D_t \text{ }, \forall\, t \in \{1,2,...,T\} \quad (2)$$

$$\sum_{k=1}^{K} x_{j,k,t} = N_j \sum_{b=1}^{T}\sum_{e=b+1}^{T} z_{b,e,t} p_{b,e,t}\, , \forall j \in \{1,2,...,J\}, \forall t \in \{1,2,...,T\} \quad (3)$$

$$\sum_{k=1}^{K} x_{j,k,t} \leq C_{k,0} + \sum_{\tau=1}^{t} C_{k,\tau}\, , \forall k \in \{1,2,...,K\}, \forall t \in \{1,2,...,T\} \quad (4)$$

$$M(1-z_{b,e,j}) \geq \sum_{n=b}^{e-1} z_{b,n} + \sum_{m=b+1}^{e}\sum_{n=m}^{e} z_{m,n}\, , \forall b \in \{1,2,...,T-1\}, \forall e \in \{b+1, b+2,...,T\}, \forall j \in \{1,2,...,J\} \quad (5)$$

$$M(1-z_{b,e,j}) \geq \sum_{m=1}^{b-1}\sum_{n=b}^{e} z_{m,n}\, , \forall\, b \in \{2,3,...,T\}, \forall e \in \{b, b+1,...,T\}, \forall j \in \{1,2,...,J\} \quad (6)$$

$$M(1-z_{b,e,j}) \geq \sum_{m=b}^{e}\sum_{n=e+1}^{T} z_{m,n}\, , \forall b \in \{1,2,...,T-1\}, \forall e \in \{b, b+1,...,T\}, \forall j \in \{1,2,...,J\} \quad (7)$$

$$z_{b,e}, f_k \in \{0,1\}, x_{j,k,t} \geq 0 \quad (8)$$

The objective function (1) is to maximize the total profit comprised of the profit from all planting areas subtracting transportation cost and the plant facility cost. The equation (2) states that the total production is equal to or more than the required demand. The equation (3) limits the total FFB transported to a plant to the total plant capacity accumulated up until period t. The equations (5), (6) and (7) prevent the land to be used more than once if it is already assigned to start planting from period *b* to *e*. The equation (8) sets up the types of variables to the desired types of decision variables. In the next section, we test the model using a small numerical example.

3. DATA COLLECTION

To simplify the planning, we divide Thailand into 6 zones: northern part, northeastern part, middle part (also include eastern and western part of Thailand) and the remaining three parts from the southern part of Thailand. We separate the southern part of Thailand into 3 zones because most of the oil palm production in on the southern part while the production is not much in other parts. For each province, we collect 2012 data of areas used for oil palm plantations (Office of Agricultural Economics, 2012) and all areas available for agriculture (Office of Agricultural Extension, 2012). The two data sets allow us to calculate the existing areas and allowable area from new oil palm plantation in all 6 zones as show in Table 1. Please note that one “rai” is equal to 0.0016 km^2 and we allot 2 millions rai for each zone for future planting area if needed. However, zone 1 does not have enough new area so all the remaining areas for agricultural activities are used. In addition, as shown in Table 1, we collect the current capacities (shown as FFB processing capacity in tons per year) and locations of FFB processing plants in Thailand from Department of Internal Trade (2011). We used the main production province in each zone to represent the location of the zone. The distances between each zone are shown in Table 2. Pleanjai and Gheewala (2009) estimated that a heavy diesel vehicle used in palm oil distribution has fuel economy of 1.628 km/Liters for truck with 20 tons load. Using the current diesel price of 29.99 baht per liter, we can estimate the transportation cost of 0.9211 baht per ton per km.

Table 1: Statistics of each zone

Zone	Province		Current Oil Palm Planting Area (Rai)	New Area (Rai)	FFB processing capacity (tons/year)
Land 1	Chumphon Ranong		848,150	380,131	3,766,800
Land 2	Surat Thani Phang Nga Phuket Nakhon Si Thammarat		1,275,400	2,000,000	5,606,400
Land 3	Krabi Narathiwat Pattani Songkhla	Satun Phatthalung Yala Trang	1,322,980	2,000,000	5,831,240
Land 4	Pathum Thani Bangkok Chainat Nonthaburi Phra Nakhon Si Ayutthaya Lopburi Saraburi Sing Buri Ang Thong Prachuap Khiri Khan Kanchanaburi Ratchaburi Samut Songkhram	Samut Sakhon Nakhon Pathom Suphan Buri Phetchaburi Chonburi Chanthaburi Chachoengsao Trat Nakhon Nayok Prachinburi Rayong Samut Prakan Sa Kaeo	442,169	2,000,000	365,000
Land 5	Chiang Rai Kamphaeng Phet Chiang Mai Tak Nakhon Sawan Nan Phichit Phitsanulok Phetchabun	Phrae Phayao Mae Hong Son Lampang Lamphun Sukhothai Uttaradit Uthai Thani	18,326	2,000,000	0
Land 6	Ubon Ratchathani Kalasin Khon Kaen Chaiyaphum Nakhon Phanom Nakhon Ratchasima Buriram Maha Sarakham Yasothon Roi Et	Loei Sisaket Sakon Nakhon Surin Nong Khai City Udon Thani Mukdahan Nong Bua Lamphu Amnat Charoen	75,598	2,000,000	0

Table 2 Distances (km.) between centers of 6 zones (ordered from Zone 1 to 6)

Distance in km	Chumpon	Suratthanee	Krabi	Prajeubkirikhan	Chaingrai	Udonthani
Chumpon	0	193	363	183	1248	1055
Suratthanee	193	0	211	364	1429	1236
Krabi	363	211	0	534	1599	1033
Prajeubkirikhan	183	364	534	0	1066	873
Chaingrai	1248	1429	1599	1066	0	1014
Udonthani	1055	1236	1033	873	1014	0

We estimated the cost to expand additional palm oil mill using the available information in the news. Table 3 shows the information and sources.

Table 3: Palm Oil Mill Capacity Expansion Cost Estimation

FFB Capacity ton/hour	Capital Investment (millions)	Capacity Expansion Cost Baht/ton(FFB)/year	Source
60	100	285.3881	Thansettakij (2012, May 18)
2	7.96	681.5068	Klinpikul S. (n.d.)
45	270	1,027.3973	Dailynews (2012, October 4)
	Average	664.7641	

Based on Thai government's 10 years renewable and alternative energy development plan (Cheokul, 2012), we obtained the demand for pure-form B100 until year 2008-2022. Pleanjai, Gheewala & Garivait (2007) showed the ratio of conversion from FFB 5.26-6.25 (with mid point = 5.755) tons to 1 ton of CPO and 1.14 tons of CPO to 1 ton of Biodiesel. Department of Agriculture stated that one liter of B100 weighs 0.88 kg per liter. Using the weight and two conversion ratios, we estimated ratio of Biodiesel: CPO: FFB (in tons) to be 1: 1.14: 6.5607 the demand of FFB per year as shown in Table 4.

Table 4: Estimated Demand of FFB

Year	Demand for B100 million liters per day	B100 weight(ton per day)	Demand for FFB (ton per day)	Demand for FFB (ton per year)
2013	3.64	3,203.20	21,015.23	7,670,560.50
2014	3.64	3,203.20	21,015.23	7,670,560.50
2015	3.64	3,203.20	21,015.23	7,670,560.50
2016	3.64	3,203.20	21,015.23	7,670,560.50
2017	4.50	3,960.00	25,980.37	9,482,835.78
2018	4.50	3,960.00	25,980.37	9,482,835.78
2019	4.50	3,960.00	25,980.37	9,482,835.78
2020	4.50	3,960.00	25,980.37	9,482,835.78
2021	5.97	5,253.60	34,467.29	12,580,562.13
2022	5.97	5,253.60	34,467.29	12,580,562.13

Lapang (2010) studied cost and benefit analysis of oil palm farming in Chumphon province. Using Lapang's study (2010), we used the varying production rates and varying profit per year from planting oil palm per rai over the life cycle of oil palm. However, we excluded the land purchased and land salvage value from our analysis because a sell at the end of cycle is uncommon for farmers.

4. RESULTS

We developed an optimization code using IBM ILOG CPLEX version 12.1 and plugged all the data gathered into the model. Figure 1 shows the result from the model. The model matches the supply of FFB to the demand very closely. In the beginning, the import of FFB or palm oil might requires due to the low production rate from young oil palm trees. However, it might be because the model assumes all the trees are planted in period 1 which might not be true in practice. Table 5 shows the total production planned each year (tons of FFB). Using the average production rate from Lapang (2010), we converted the production to the amounts of land needed as shown in Table 6. Figures 2-7 shows the productions (ton of FFB) from each zone for all six zones. The amount of cumulative production is higher as the period increases due to the increasing demand.

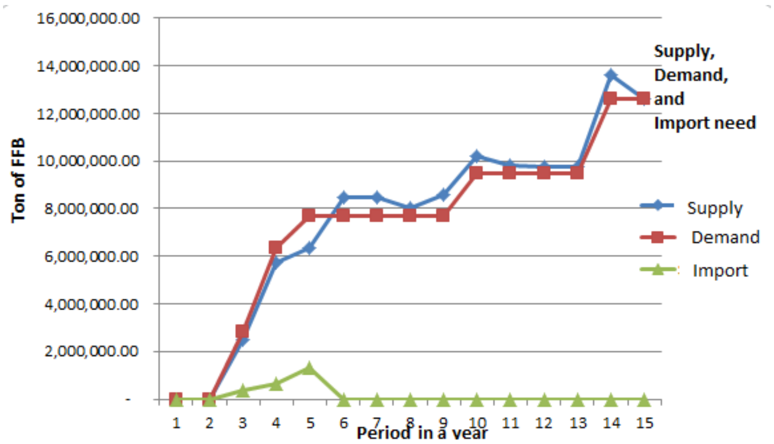

Figure 1: Supply and demand matching

Table 5: Total production planned each year

period	Year	Production planned (Ton of FFB)
1	2008	-
2	2009	-
3	2010	2,470,820.00
4	2011	5,721,722.00
5	2012	6,335,962.00
6	2013	8,455,214.12
7	2014	8,455,213.47
8	2015	8,007,712.00
9	2016	8,581,413.00
10	2017	10,197,363.00
11	2018	9,816,173.41
12	2019	9,732,730.41
13	2020	9,732,730.41
14	2021	13,619,357.54
15	2022	12,601,652.00

Table 6: Total area needed in each period

period	Total additional area need(Rais)
1	-
2	-
3	610,079.01
4	1,412,783.21
5	1,564,435.06
6	2,087,707.19
7	2,087,707.03
8	1,977,212.84
9	2,118,867.41
10	2,517,867.41
11	2,423,731.71
12	2,403,143.31
13	2,403,143.21
14	3,362,804.33
15	3,111,519.01

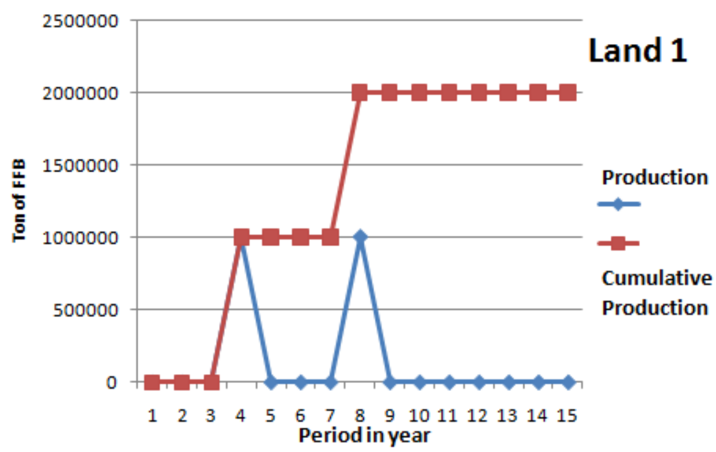

Figure 2: Production of the Land 1

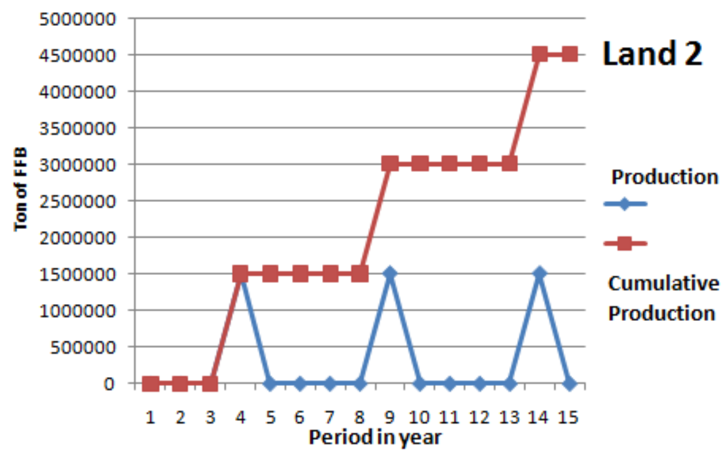

Figure 3: Production of the Land 2

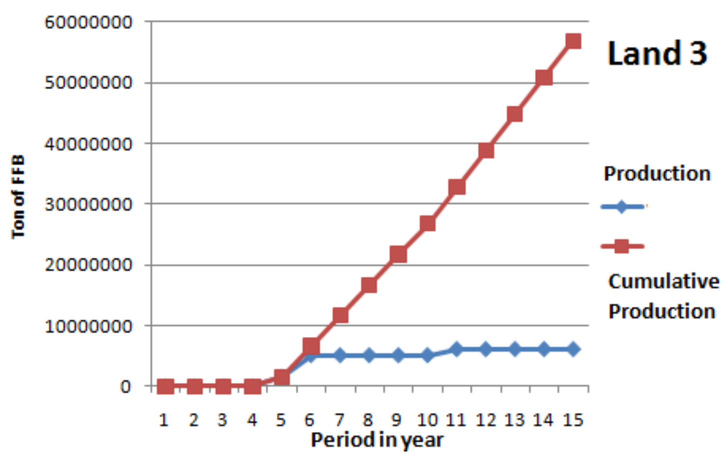

Figure 4: Production of the Land 3

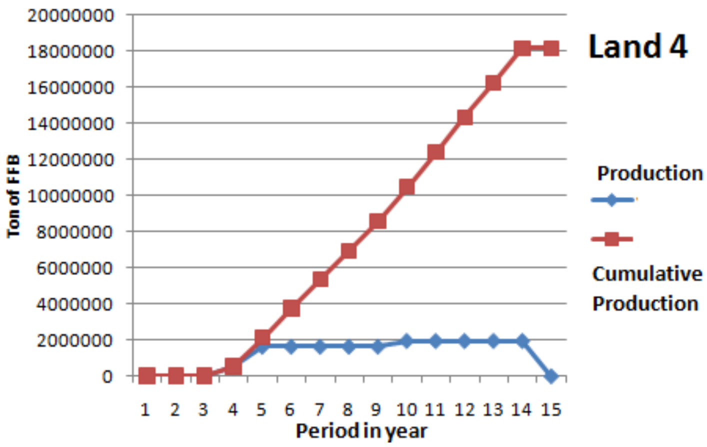

Figure 5: Production of the Land 4

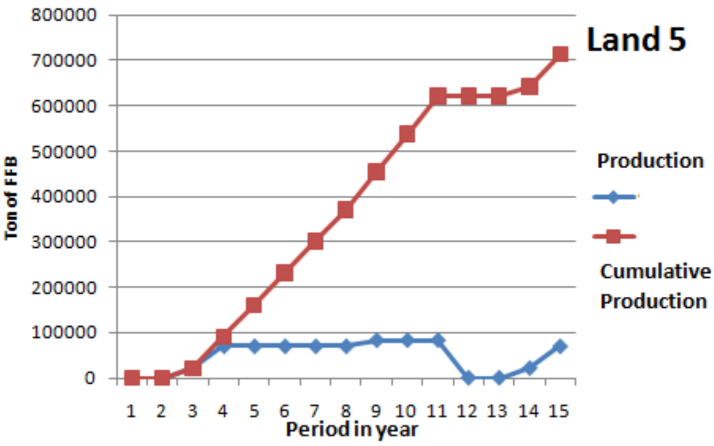

Figure 6: Production of the Land 5

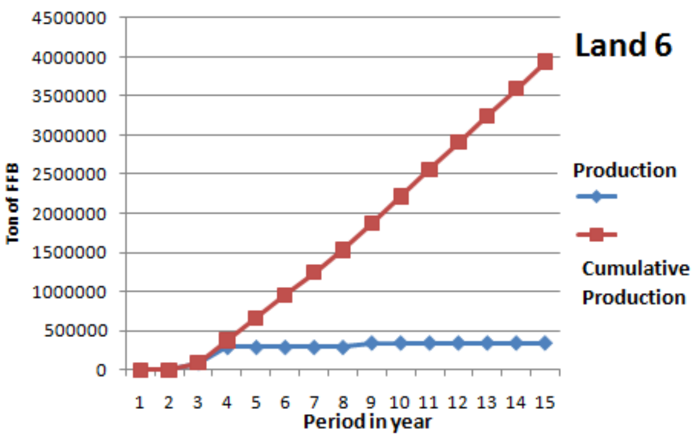

Figure 7: Production of the Land 6

Figures 8-12 shows that production needed from additional land need for planting oil palm at Land 1-5. At Land 6, no additional land is needed.

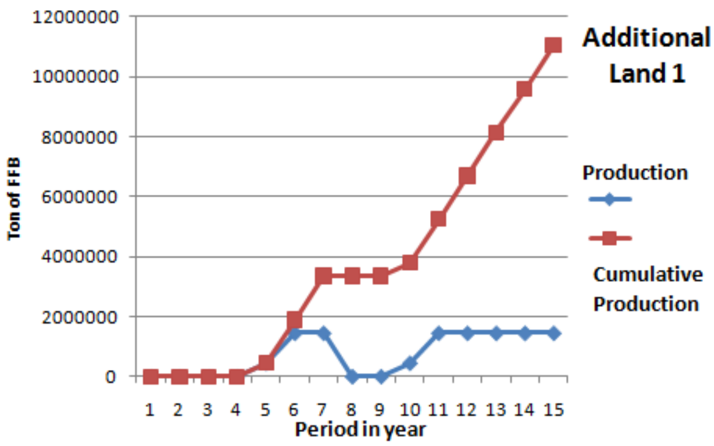

Figure 8: Production of the additional land at Land 1

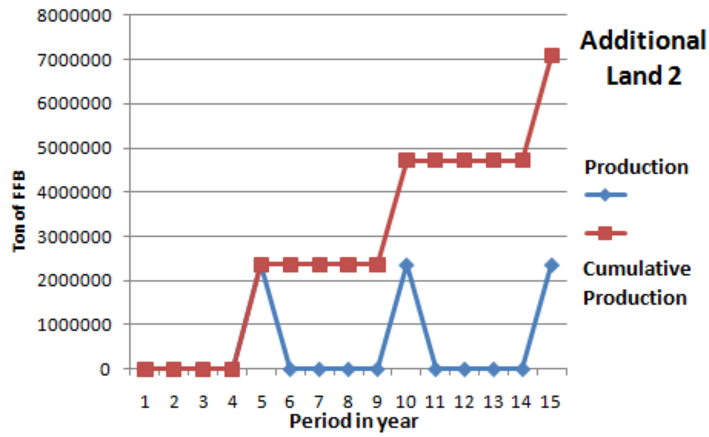

Figure 9: Production of the additional land at Land 2

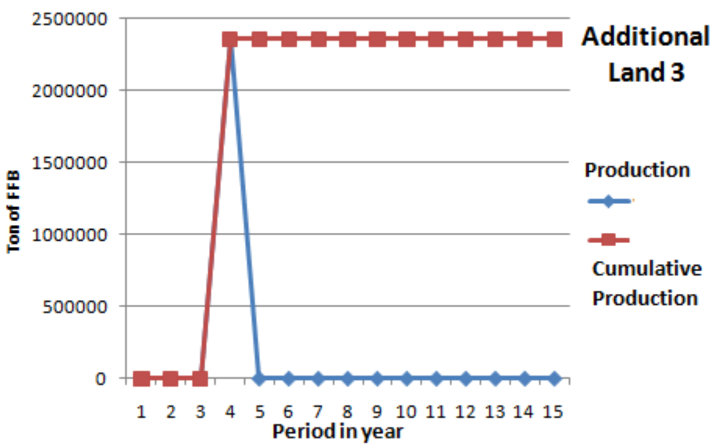

Figure 10: Production of the additional land at Land 3

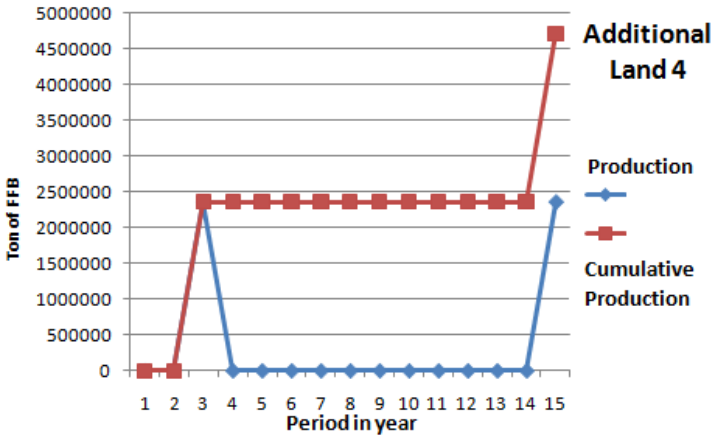

Figure 11: Production of the additional land at Land 4

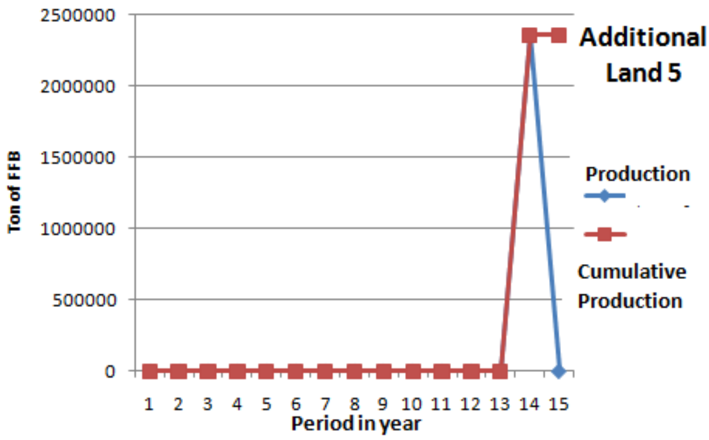

Figure 12: Production of the additional land at Land 5

Also, the model suggested to add new oil palm mill with processing capacity of 220,030 tons in period 6 at the Land 1, 2,696,800 tons in period 6 at Land 3 and 363,300 tons in period 6 at Land 5. In total, a new plant capacity of 3,280,130 tons is needed in period 6. No new plants are needed in other areas. Figure 13 shows the total new capacities needed in year period.

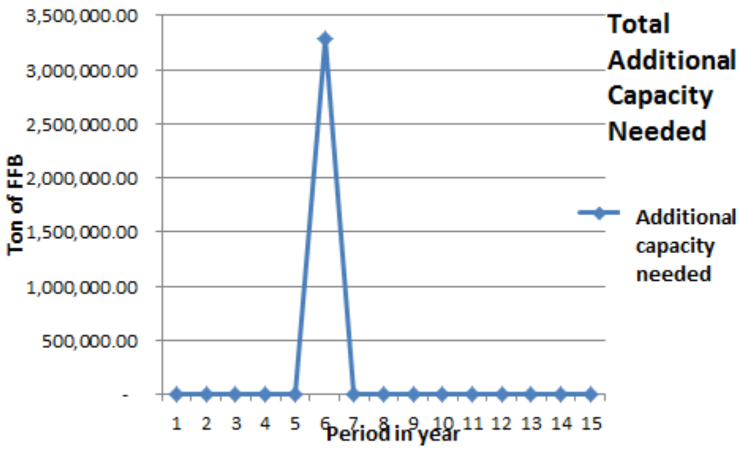

Figure 13: Total new capacities needed

5. CONCLUSION

Due to the increasing demand of biodiesel as a result of Thai government alternative energy policy, Thailand faces the shortage of palm oil production and processing capacity. We developed a mathematical model to help planning of oil palm production, transportation and oil palm mill capacity and locations so that the demand can be satisfied with minimal production, logistics and facility costs. To provide the guideline for Thailand, we collected secondary data from various sources to plug into the model. The model is solved using IBM ILOG CPLEX version 12.1. The result shows that the model works well to closely match supply with the increasing demand. The model also suggests the required planting areas to be prepared and the additional capacity to be installed for all zones of Thailand. Without the new land and processing plant, Thailand will face the shortage of supply and capacity to meet the goal. In the numerical test, we found the model has difficulty solving large-scale problems and the number of lands has to be limited. Also, the accuracy of data is crucial to provide the accurate plan for Thailand. In the future study, the model will be simplified and more detailed data will be collected.

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