EFFICIENCY ANALYSIS OF RSPO OIL PALM FARMS IN THAILAND

BY

ANUAPRP SAENGSATHIEN

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF MASTER OF
ENGINEERING (LOGISTICS AND SUPPLY CHAIN SYSTEMS
ENGINEERING)
SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
THAMMASAT UNIVERSITY
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A Thesis Presented

By
ANUPARP SAENGSATHIEN

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Abstract

EFFICIENCY ANALYSIS OF RSPO OIL PALM FARMS IN THAILAND

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According to Roundtable on Sustainable Palm Oil (RSPO), Thailand is the first oil palm producer in the world to achieve independent smallholders RSPO-certified under the RSPO Group Certification in 2012. The purpose of this study was to measure technical efficiency, cost efficiency, allocative efficiency and to identify factors affecting cost efficiency in RSPO oil palm plantation in Thailand. The RSPO record book from 2014 was analyzed using data envelopment analysis method in value-based cost efficiency model of Tone (2002). The estimated technical efficiency, cost efficiency and allocative efficiency of RSPO oil palm farms were found to be 86.04, 55.08, and 63.40 percent, respectively. The result of ordinary least square regression revealed that the important factors showing positive relationship on cost efficiency are applied empty fresh fruit bunch on the ground of oil palm farm and payment for water supply such as artesian well.

Keywords: Roundtable on Sustainable Palm Oil (RSPO), Data Envelopment Analysis, Ordinary Least Square Regression

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Chapter 1
Introduction

1.1 Overview of oil palm farm in Thailand

Palm oil is vegetable oil traded worldwide. In terms of production and consumption, palm oil is the world’s leading vegetable oil. Global consumption of palm oil was 52.1 million tons in 2012. In Thailand, production of oil palm can satisfy all of domestic demand in various fields. Most of producers in Thailand is agriculturists and small entrepreneurs that lead to higher oil palm production cost than the big producers such as Malaysia and Indonesia. Palm oil demand is highly increasing in the global market. Oil palm is used as raw material in thousand products currently on the market. The suitable area for oil palm plantations are located at latitude 10 north - south of the equator or up to latitude 20 north - south of the equator. This makes ASEAN countries, especially Malaysia and Indonesia to become the world's main producers of palm oil. Thailand locates in one of the suitable areas for oil palm plantations. This plantation area in Thailand has been increasing constantly with an average annual growth rate of 11% from 1981 to 2000 and 9% from 2001 to 2010 (Dallinger, 2011). However, the rapid expansion of oil palm plantation worldwide is due to high demand of oil palm that could lead to deforestation, environmental problem and biodiversity. However, no report is found on the negative effect of oil palm plantation expansion in Thailand (Wangrakdiskul & Yodpijit, 2013). Malaysia and Indonesia are the world's main oil palm producers that are continually expanding their plantation areas. Following the increase in oil palm plantation area, some forests were changed into oil palm farms (Fitzherbert et al., 2008). The United Nations Environment Program (UNEP) then declared oil as the main driver of deforestation in both countries.

Thailand is the third largest palm oil producer in the world. The plantation of oil palm in Thailand was 95% from smallholder farmers produce and only 5% of plantation owned by crushing mill and private company (Department of International Trade 2013). Three main cultivation areas in Thailand are Chumporn, Krabi and Suratthani. The production performance in Thai oil palm is still lower than competitors. OER (Oil Extraction Rate) of Thailand oil palm industry is about 15.7% but 20.2% for Indonesia and 19.3% for Malaysia. This is because of the lack of skill labors in harvesting mature fresh fruit bunch. The ratio of yield of fresh fruit bunch to plantation area is 14.5 ton/hectare. This is still low because most of the plantation is in low scale area (Kasikorn Research Center).

In the past twenty years, OER in Thailand has been showing a declining trend (Dallinger, 2011). From 1990 to 1994, the average OER was 18 percent. From 2005 to 2009, the average OER was 16.6 percent which represents the decreasing in OER of about 2 percent. OER in palm oil milling operation depends on various factors such as the delivery of fresh fruit bunch from oil palm farm to palm oil mill organized by intermediaries. There, intermediaries collect and combine the harvest of many smallholders to send into bigger truck loads. Normally, intermediaries do malpractice such as watering down the fresh fruit bunch or adding sand or soil to increase the weight of fresh fruit bunch which leads to deterioration of fresh fruit bunch quality. If the quality of processed fresh fruit bunch is low, the oil extraction rate in palm oil mill will be of low quality.

Table 1.1: The oil palm plantation cost in Thailand, 2002-2015

Year	Variable Cost	Fixed Cost	Total Cost		
	(Baht/Rai)	(Baht/Rai)	(Baht/Rai)	(Baht/Ton)	(Baht/Kg)
2002	2580.91	700.23	3,281.14	1350	1.35
2003	2759.43	696.88	3,456.31	1270	1.27
2004	2676.8	700.23	3,377.03	1260	1.26
2005	3,438.88	700.23	4,139.11	1680	1.68
2006	3,626.41	700.23	4,326.64	1530	1.53
2007	3,703.90	700.41	4,404.31	1840	1.84
2008	5,899.87	947.83	6,847.70	2130	2.13
2009	5,996.52	947.65	6,944.17	2712.57	2.71
2010	5,730.61	1,135.47	6,866.08	2970	2.97
2011	6,736.10	1,244.31	7,980.41	2770	2.77
2012	7,302.82	1,399.25	8,702.07	2850	2.85

Year	Variable Cost	Fixed Cost	Total Cost		
	(Baht/Rai)	(Baht/Rai)	(Baht/Rai)	(Baht/Ton)	(Baht/Kg)
2013	7,228.83	1,459.64	8,688.47	2640	2.64
2014	7,237.36	1,690.80	8,928.16	2840	2.84
2015	7,098.90	1,853.06	8,951.96	3130	3.13

Source: Office of Agricultural Economics, 2015

As illustrates in the Table 1.1, oil palm plantation cost in Thailand tends to increase. Cost structure of oil palm plantation can be classified into two categories of fix costs and variable costs (Nillaket & Wattanakul , 2014). Fix costs include land rental cost, land tax, mechanic and tool depreciation. Variable costs include hired labor cost, harvesting cost, chemical and natural fertilizer cost, pesticide cost, herbicide cost, transportation fuel, mechanic and tool maintenance cost, oil palm seedling and maintenance oil fuel. Smallholder farmers and entrepreneurs in the oil palm business need to improve oil palm productivity. Since the growers, mills and refineries purified by focusing on cost reduction and increasing of the production yield. To keep prices competitive with imported palm oil, oil palm growers should focus on improving crops to achieve a higher crop yield per area. This can be done by selecting the proper cultivation terrain and appropriate climate including selective seedling. In order to cultivate a high rate of oil extraction, one needs to study the period of apply and type of fertilizer in each age group of palm trees, to prune oil palm frond as well as to plan oil palm plantations as a replacement of older trees that give lower yield.

1.2 RSPO oil palm farm in Thailand

Using credible global standards and engagement of stakeholders, the Roundtable on Sustainable Palm Oil (RSPO) has been formed to promote the growth and use of sustainable oil palm products since 2004. In order to create the norm on sustainable oil palm, RSPO targets transformation of the markets. Community enterprise group for sustainable palm oil production (Chonburi), community enterprise group Suratthani, the sustainable oil palm smallholders’ production (Univanich Plaipraya) and UPOIC Nuakhlong-Khaopanom are the very first groups of independent smallholders to achieve RSPO Certification (Wangrakdiskul & Yodpijit, 2013). These four groups participated in "Sustainable Palm Oil Production" project which took three and a half years from January 2009 to June 2012. This project aimed to implement the principles of RSPO certification and requirements to smallholder oil palm farmers in Thailand which was supported by German Academy for International Cooperation (GIZ). By implementing the RSPO standard, the oil palm smallholder farmers have experienced an increase in fresh fruit bunch production.

1.3 Objective

This research study measured the technical efficiency, cost efficiency and allocative efficiency as well as investigated factors affecting cost efficiency of RSPO oil palm farmers in Thailand. The objectives of this study were

1. To estimate the best practice or production frontier of oil palm farm using data envelopment analysis technique.
2. To apply suitable data envelopment analysis technique to problem under study
3. To review previous researches on the application of data envelopment analysis technique in different fields
4. To investigate factors affecting cost efficiency

1.4 Overview of thesis

There are five chapters in this thesis, which are as follows:

Chapter 1 is the introduction part which includes an outline of oil palm farm in Thailand and RSPO oil palm farm in Thailand, objective and overview of the thesis.

Chapter 2 is the literature review part. It consists of the discussions about the past researches done on the efficiency measurement in agricultural field.

Chapter 3 is the methodology part. In this part, the DEA mathematical model and regression analysis model are presented.

Chapter 4 is the result and discussion part. Results are presented and discussed.

Chapter 5 is the conclusion and recommendation for further study.

Chapter 2
Literature Review

2.1 Definition of efficiency

The ratio of output to input was simply defined as efficiency. Data envelopment analysis (DEA) is non-parametric approach to indicate relative efficiency of a set of decision making units (Atici & Podinovski). When the concept of efficiency measurement study was applied in DEA method, three different efficiency measures can be determined namely the technical efficiency, allocative efficiency and economic efficiency. These can be described as follow (Farrell, 1957; Phitthayaphinant & Somboonsuk, 2013):

2.1.1 Technical Efficiency

The technical efficiency can be defined as a degree to which a decision making unit produces the maximum feasible production output from a given bundle of inputs or uses the minimum feasible amount of inputs to produce a given amount of output. In agriculture field, technical efficiency refers to the ability of farmers in using the least amount of inputs to achieve the productivity level required or in producing as many as they can under the existing production technology. For oil palm plantation, it means the comparison between the actual yield obtained from the use of inputs and the highest yield possible. Farmers with higher or equal yield under fewer inputs than others show higher technical efficiency in producing oil palm.

2.1.2 Allocative Efficiency or Price Efficiency

The price efficiency is the decision making unit's ability to produce a given level of output using cost minimizing input ratios. In agricultural area, price efficiency refers to the ability of farmers in allocating mix of inputs to achieve lowest production cost or highest profit under the existing production technology and the supply cost faced. Price efficiency can be called allocative efficiency when comparing production cost spent at a time point with the least possible production cost. In comparison with other farmers producing the same amount of output, the one using appropriate amount and similar quality of inputs under comparable production technology but with lower cost of inputs or higher profits show higher price efficiency in producing oil palm.

2.1.3 Cost Efficiency or Economic Efficiency

The economic efficiency is the decision making unit's ability to produce predetermined quantity of output at a minimum cost. Besides, this efficiency type can be defined as a product of technical efficiency and allocative efficiency. Within a field of agriculture, cost efficiency refers to the ability of farmers in running oil palm farm by allocating mix of inputs and using most appropriate production process to achieve lowest production cost and highest yield at certain supply cost and production technology. It can be said as the ability of farms in producing oil palm at the level of having both technical efficiency and allocative efficiency at the same time.

2.2 Previous studies in agriculture efficiency measurement and the other fields

The majority of literature on agriculture efficiency measurement used either parametric or non-parametric approaches. Sharma et al. (1997) proposed a comparison between stochastic production frontier and data envelopment analysis in examining the performance of Hawaii's swine industry for improvement and identifying the source of inefficiency. The data envelopment analysis was confirmed to be more straightforward than the stochastic production frontier.

Kazim Baris Atici and Victor V. Podinovski reviewed research studies on data envelopment analysis applied in agricultural field. Cost was proposed as key factor which is normally determined as input in agriculture data envelopment analysis studies. Wirat (2001) analyzed technical efficiency, scale efficiency and pure technical efficiency of oil palm farm in Thailand using input-oriented DEA approach. This research study revealed two important results. First, thirty-two percent of overall technical inefficiency can be reduced by adopting the best-practice to decrease pure technical efficiency and by operating oil palm farm at optimal scale. Second, scale efficiency of oil palm farm makes large high contribution to the overall inefficiency.

While, the input-oriented DEA was used by Eyitayo et al. (2011) to examine the technical efficiency of cocoa farms in Cross River State in Nigeria. This study recommended that training should be provided to farmers to support suitable combination of input resources. Ibitoye et al. (2011) examined factors influencing oil palm production in Ondo state by using regression analysis. The result revealed that only two variables have significant relationship with the fresh fruit bunch production including the level of education attained and the number of times the respondents attended training.

Banaeian et al. (2011) investigated both technical efficiency and scale efficiency of greenhouse strawberry in Iran. This research study used aggregated inputs to distinguish between technical and allocative effects. However, this may lead to failure. The multi-stage DEA was applied to overcome this. Multi-stage DEA method was used for invariant to unit measurement and to identify representative efficient point. By using DEA as a benchmark tool, the inefficient greenhouses can recognize resources that should be changed to increase their performance. The result revealed that 29 percent of fertilizer cost can be saved through the improvement of management practices.

Taraka et al. (2010) combined DEA with tobit regression analysis to investigate the efficiency of rice farms in central Thailand in crop year between 2009 and 2010. The result revealed that family labors, extension service by extension officers, certified seed used, weedy rice and insect infestation were the main key factors affecting technical inefficiency. Taraka et al. (2014) applied stochastic frontier to measure technical efficiency of rice farms in central Thailand in crop year between 2009 and 2010. The significant result showed that gender, farming experience, GAP certificate and cropping intensity affected technical efficiency statistically. Bozoğlu and Ceyhan (2007) recommended that many policies should be used to support better extension service, farmer training program and access to credit for example, to enhance the technical efficiency level. Tipi et al. (2009) measured both technical efficiency and scale efficiency and investigated the determinants of efficiency of rice farm in Marmara region in Turkey through the use of input-oriented DEA and tobit regression analysis. The result revealed that farm size and membership of co-operative showed positive relationship with technical efficiency.

In previous studies, various literatures (B.H. Gabdo, 2013; Z. Bayramoglu and E. Gundogmus, 2008) employed traditional cost efficiency model proposed by Färe et al. (1985) to estimate cost efficiency. B.H. Gabdo (2013) applied DEA to measure cost efficiency and allocative efficiency of smallholder livestock-oil palm integration farms in Johor, Malaysia. The DEA method in traditional cost efficiency model by Färe et al. (1985) was employed. The result revealed that in order to improve cost and allocative efficiency, livestock-oil palm integration farmers should carefully purchase production input at cheaper rate and be prudent.

In South Sumatra Indonesia, Malini and Aryani (2012) analyzed the efficiency level of plantation and compared the income of RSPO certified and without RSPO certified using applied mathematical calculations and statistical methods. The result revealed that smallholder farmers in oil palm plantation with RSPO certified had higher income than the one without RSPO certified. Both land expansion and capital influenced oil palm plantation with RSPO certified while only land expansion had an influence on the plantation without RSPO certified.

However, this study, to our knowledge, is the first to employ DEA method in value-based technical, value-based cost, value-based allocative efficiencies model of Tone (2002) to estimate technical efficiency, cost efficiency and allocative efficiency at farm level in Thai agriculture.

2.3 Data envelopment analysis (DEA)

Data envelopment analysis (DEA) was first introduced by Charnes et al. (1978) who worked to measure the efficiency of decision making units. It uses linear prog02ramming method to construct production frontier of a set of decision making units and to measure the relative technical efficiency of each DMU. This approach also identifies efficient production unit. Data envelopment analysis is a non-parametric programming technique that requires a few priori assumptions concerning the functional relationship between input and output. That also develops production frontier or best practice by optimizing the weighted output/input ratio of each decision making unit.

2.3.1 The advantage of data envelopment analysis

The main strength of DEA model is to generate new alternatives to enhance performance compared with other methods. The backbone of the DEA technique is linear programming based on optimization platform. The strength of DEA over the other methods is to identify the optimal ways of performance rather than the average number that lead to benchmarking in a normative approach. The main advantages of DEA are in the following:

1. Source of inefficiency can be identified, analyzed and quantified for all evaluation units.
2. Mathematical formulation form does not require to be specified for production function.
3. The DEA results indicate the peer group for decision making unit which are not observed to be efficient. This is useful for inefficient DMU to site study efficient DMU.

2.3.2 The limitations of data envelopment analysis

1. DEA only evaluates efficiency relative to best practice or efficiency frontier within the particular set of sample. It cannot compare the efficiency scores between two different groups of study
2. DEA shows the result that especially responsive to measurement error in which stochastic frontier analysis has strength over DEA
3. Input, output and the size of sample make DEA score sensitive. If we increase the sample size, the average efficiency score will be decreased. Because increasing sample size lead to DEA work for higher scope to find the comparison organization.

The limitation of DEA must be recognized. Despite these limitations, there is still potential benefit in using DEA to strength forward understanding the oil palm farm performance and potential ways to improve farm. The measure of inputs and output must be inclusive as much as possible.

2.4 Ordinary regression analysis

Most of past literature studies employed the Tobit regression model (TRM) to explore factors affecting efficiency in agriculture field (Traka et al. 2010; Tipi et al. 2009; Wirat, 2004). However, McDonald (2009) argued that DEA efficiency score is fractional data and not generated by a censoring process. Then, TRM is not appropriate in this situation. According to Banker and Natarajan (2008), using ordinary regression analysis in second stage DEA to explore factors affecting efficiency level will obtain better results than using TRM.

2.5 Principles of farmer certification

Farmer certification consists of 8 principles and 39 criteria. The principles and main requirement are presented in the following (Wangrakdiskul &Yodpijit, 2013, RSPO, 2013):

Principle 1 Commitment to transparency: Oil palm farmers provide information to public on environmental, social and legal issues.

Principle 2 Compliance with relevant laws and regulations: Oil palm farmers concern with laws, regulations and the right of land use through legal advice, documents and records.

Principle 3 Commitment to long term economic and financial viability: Oil palm farmers implemented the plan concerning financial advice, R&D or extension service for long term economic and financial viability management.

Principle 4 Use of appropriate best practices by growers and millers: Oil palm farmers are required to manage the appropriate manner by performing good operation, maintaining the soil fertilizer, maintaining the ground/surface water and soil quality, adopting Integrated Pest Management (IPM), preventing the environment, occupational health and safety, and training members in farms.

Principle 5 Environmental responsibility and conservation of natural resources and biodiversity: Oil palm farmers concern with the reduction, recycling, reuse and disposal of waste. The burning of disposed wastes should be avoided. The use of renewable energy should be maximized.

Principle 6 Recognition of the employees' right: The sexual harassment is prevented. Child labor is prohibited. Oil palm farmers must respect human right.

Principle 7 Responsible development of new plantings: Oil palm farmers are required to publicly announce before launching new plants and avoid the use of fire for preparation of new plantings.

Principle 8 Commitment to continuous improvement in key areas of activity: Oil palm farmers regularly monitor and review activities, perform third party audits and provide trainings for farmers.

Chapter 3

Research Methodology

3.1 Data sources

The main data source used in this study was secondary data provided by RSPO record books of oil palm farmer members. This research study was conducted in Suratthani province which is main province of oil palm plantation, constituted in the study sample. To construct the production efficient frontier, the inputs and output variables were defined for calculation of the efficiency score. The data collection for this research was the 2014 oil palm crop year (January-December). To measure the technical efficiency, cost efficiency and allocative efficiency in oil palm production, the output considered was fresh fruit bunch quantity harvested in metric ton. While, the five important inputs were fertilizer cost, hired labor, transportation and fuel cost, harvesting cost and other input cost. The variables used in valued-based model of Tone (2002) were summarized in the Table 3.1.

Table 3.1: Variable definitions and measurement for technical efficiency, cost efficiency and allocative efficiency

Variables	**Units**	**Definition**
Fresh Fruit Bunch Production	Metric Tons/ha	Quantity of oil palm production
Fertilizer cost	Baht/Ton.FFB	Cost incurred for applying fertilizer
Hired labor	Baht/Ton.FFB	Cost incurred for hired labor
Transportation & Fuel cost	Baht/Ton.FFB	Cost incurred for transportation and fuel usage
Harvesting cost	Baht/Ton.FFB	Cost incurred for harvesting fresh fruit bunch
Other input cost	Baht/Ton.FFB	Total cost incurred for all variable expenses, except the above inputs

3.2 Data analysis

Two mathematical techniques were applied in two stages as analytical tools in this research study:

3.2.1 Measuring technical efficiency, cost efficiency and allocative efficiency using Data Envelopment Analysis (DEA)

Data envelopment analysis was used for measuring the technical, cost and allocative efficiency of oil palm farm in the sample data. In the first stage, technical, cost and allocative efficiency scores were calculated by using input-oriented variable return to scale DEA. The technical efficiency scores and cost efficiency scores in this research study were estimated by using computer program, IBM ILOG CPLEX Optimization software.

The following was done in order to analyze the cost efficiency of RSPO oil palm farms in Southern Thailand. In this study, n observed decision making units (DMUs) were dealt with; each uses m input to produce s output. Let $x_j = (x_{1j}, \ldots, x_{mj})^T \in \mathbb{R}^m_{\geq 0}$ and $y_j = (y_{1j}, \ldots, y_{sj})^T \in \mathbb{R}^s_{\geq 0}$ be the input and output vectors of DMU$_j$, respectively with $j \in J = \{1, \ldots, n\}$. Let $c_j = (c_{1j}, \ldots, c_{mj})^T \in \mathbb{R}^m_{\geq 0}$ be the non-negative price vectors of inputs of DMU$_j$. The input-spending of each DMU$_j$ was assumed to be $\bar{x}$, where $\bar{x} = c * x$. Here, $*$ was the component-wise multiplication of vectors. The cost efficiency of the evaluated oil palm farm was measured as the ratio of the minimum cost to the actual cost. In the following model of Sahoo et al. (2014), it comprises of cost efficiency model of Färe et al. (1985) and value-based model of Tone (2002):

Cost efficiency model of Färe et al. (1985)

$$\gamma_o = Min_{\lambda,x} = \frac{1}{C^o}\sum_{i=1}^{m} c_{io}x_i$$

$$subject\ to$$

$$\sum_{j\in J}\lambda_j\, x_{ij} \;\le\; x_i, \qquad i = 1, \dots, m,$$

$$\sum_{j\in J}\lambda_j\, y_{rj} \;\ge\; y_{ro}, \qquad r = 1, \dots, s,$$

$$\sum_{j\in J}\lambda_j = 1,$$

$$\lambda_j \;\ge 0, \forall j\; \in J,$$

where $C^o = \sum_{i=1}^{m} c_{io}x_{io}$ is the observed cost of $\mathrm{DMU_o}$

The concept of cost efficiency originated by Farrell (1957) was then further developed using linear programming technique by Färe et al. (1985). In their study, each oil palm farmer used different kinds of herbicide, fertilizer usages and purchased the inputs with different prices. The cost efficiency DEA model by Färe et al. (1985) can be limited because this model assumed the same input prices across all decision making units (DMUs) and homogeneous (physical) inputs. In order to keep away from this weak point, the value-based technology in DEA is appropriate to applied. Then, the value-based cost efficiency model of Tone (2002) was employed in this study.

Value-based cost efficiency model of Tone (2002)

$$\gamma_o^{CE} = Min_{\lambda,\bar{x}}\frac{1}{C^o}\sum_{i=1}^{m}\bar{x}_i$$

$$subject\ to$$

$$\sum_{j\in J}\lambda_j\, \bar{x}_{ij} \;\le\; \bar{x}_i, \qquad i = 1, \dots, m,$$

$$\sum_{j\in J}\lambda_j\, y_{rj} \;\ge\; y_{ro}, \qquad r = 1, \dots, s,$$

$$\sum_{j\in J}\lambda_j = 1,$$

$$\lambda_j \;\ge 0, \forall j\; \in J,$$

where $C^o = \sum_{i=1}^{m}\bar{x}_{io}$ is the observed cost of $\mathrm{DMU_o}$

Let γ_o^{CE} denotes the value-based cost efficiency score having a value $0 < \gamma_o^{CE} \leq 1$. If the γ_o^{CE} is equal to one, it means that the farm is on the frontier. The vector λ_j is non-negative vector of weights which indicate the linear combination of the peers of the j-th farm. m is the number of inputs, s is number of outputs, n is number of DMUs (j = 1,…,n), y_1 represents the fresh fruit bunch production output, $\sum_{i=1}^{m} \bar{x}_i$ is the minimum cost which $\bar{x}_1$ represents fertilizer cost, $\bar{x}_2$ represents harvesting cost, $\bar{x}_3$ represents transportation and fuel cost, $\bar{x}_4$ represents hired labor cost and $\bar{x}_5$ represents other input cost. y_{ro} represents r^{th}output for DMU$_o$ (DMU$_o$ represents decision making units under evaluation). To obtain value-based cost efficiency score (γ_o^{CE}) for each farm in the sample, the linear programming problem need to be solved n times. Here, IBM ILOG CPLEX Optimization software was used to execute data envelopment analysis.

In addition, the input-oriented value based TE measure, ρ_0^{IVTE}, can be set up as

$$
\begin{aligned}
&\rho_0^{IVTE} = Min_{\lambda,\bar{\theta}}\ \bar{\theta} \\
&s.t. \\
&\sum\nolimits_{j \in J} \lambda_j\, \bar{x}_j \ \leq\ \bar{\theta}\bar{x}_{io}, i = 1, \dots, m, \\
&\sum\nolimits_{j \in J} \lambda_j y_{rj} \ \geq\ y_{ro}, r = 1, \dots, s, \\
&\sum\nolimits_{j \in J} \lambda_j = 1, \lambda_j \ \geq 0, \forall j\ \in J,
\end{aligned}
$$

Obviously, one can have the following relationship: $\gamma_o^{CE}\ \leq\ \rho_0^{IVTE}\ \leq\ 1$, Using this equation: $\gamma_o^{CE}\ \leq\ \rho_0^{IVTE}\ \leq\ 1$, one can define the input-oriented AE (price efficiency) as $\alpha_o^{IAE} = \frac{\gamma_o^{CE}}{\rho_0^{IVTE}}\ \leq\ 1$, From this equation: $\alpha_o^{IAE} = \frac{\gamma_o^{CE}}{\rho_0^{IVTE}}\ \leq\ 1$, the CE measure, γ_o^{CE}, can be expressed as the product of the (input-oriented) value-based AE and TE as the following:

$\gamma_o^{CE} = \alpha_o^{IAE} \times \rho_0^{IVTE}$, Decision making unit will be cost efficient ($\gamma_o^{CE} = 1$) if the both value-based technical efficient and allocative efficient. If $\gamma_o^{CE} < 1$, it incurs higher costs due to not being able to use.

3.2.2 Regression analysis

In the 2nd stage after the cost efficiency was obtained by using DEA, OLS regression analysis was used to explain variation in efficiency measurement of RSPO oil palm farm, to determine the cause of efficiency and to analyze factors affecting the cost efficiency. In this research study, the cost efficiency score obtained from the DEA model in the first stage that considers the variable return to scale input-oriented model was applied to explore the relationship between the cost efficiency and its determinants. The cost efficiency score was selected as the dependent variable. This cost efficiency score as dependent variable was regressed against explanatory variables as independent variables. The explanatory variables were classified into four categories including demographic variables and farm management characteristics, age variables, location variables and fertilizer variable. The standard ordinary least squares regression model can be specified as

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n + \varepsilon$$

Where:

- Y is dependent variable
- β_0 is the intercept term
- β_i are unknown parameters to be estimated
- ε is the error term

The ordinary regression model was formulated as:

$$C.E_i = \beta_0 + \beta_1 GEND_i + \beta_2 AGE_i + \beta_3 FSIZE_i + \beta_4 NHERB_i + \beta_5 AEFFB_i + \beta_6 AGE1_i + \beta_7 AGE2_i + \beta_8 PAID_i + \beta_9 WCOURSE_i + \beta_{10} MAPUI_i + \varepsilon$$

Where:

- $C.E_i$ is value-based cost efficiency score for i^{th} RSPO oil palm farm
- β_0 is the constant term
- β_1-β_{10} are the coefficients of the explanatory variables or unknown parameters to be estimated
- ε is the error term

Explanatory variables were classified into four categories. The information obtained from the samples of RSPO oil palm farms by using RSPO record books can be shown in the following:

1. Demographic variables and Farm Management Characteristics

1. GEND	Gender (Male=1, Otherwise=0)
2. AGE	Age of oil palm farmer (year)
3. FSIZE	Farm Size (hectares)
4. NHERB	Non-herbicide applied (Yes=1, Otherwise=0)
5. AEFFB	Applied empty fresh fruit bunch (Yes=1, Otherwise = 0)

2. Age variables

6. AGE1	Age of oil palm 3 to 8 years (Yes=1, Otherwise = 0)
7. AGE2	Age of oil palm 9 to 19 years (Yes=1, Otherwise = 0)

3. Location Variables

8. PAID	Paid for water-supply (Yes=1, Otherwise=0)
9. WCOURSE	Watercourse in oil palm plantation (Yes=1, Otherwise=0)

4. Fertilizer Variable

10. MAPUI	Applied strange fertilizer (Yes=1, Otherwise=0)

The MINITAB 17.0 computer program was used for the OLS regression analysis to estimate the parameters by using maximum likelihood method.

Table 3.2: Type of explanatory variables and expected signs of coefficients

Coefficient	Explanatory Variable	Type of variable	Expected sign of coefficient
β_1	GEND	Dummy	positive or negative
β_2	AGE	Continuous	positive or negative
β_3	FSIZE	Continuous	negative
β_4	NHERB	Dummy	positive or negative
β_5	AEFFB	Dummy	positive
β_6	AGE1	Dummy	negative
β_7	AGE2	Dummy	positive
β_8	PAID	Dummy	positive
β_9	WCOURSE	Dummy	positive or negative
β_{10}	MAPUI	Dummy	positive

- Farm size was expected to have negative relationship with the cost efficiency
- Applied empty fresh fruit bunch was expected to have positive relationship with the cost efficiency
- Age of oil palm from 3 to 8 years was expected to have negative relationship with the cost efficiency
- Age of oil palm from 9 to 19 years was expected to have positive relationship with the cost efficiency
- Paid for water-supply was expected to have positive relationship with the cost efficiency
- Applied strange fertilizer was expected to have positive relationship with the cost efficiency

Chapter 4

Result and Discussion

4.1 Descriptive analysis of data

Data was collected from record books of RSPO oil palm farmer members in Suratthani, Thailand in September, 2015. The data gathered for the 2014 cost of input-spending and oil palm production. Data was gathered from 116 oil palm farms from 66 smallholder farmers of RSPO oil palm farms. So finally data from 78 oil palm farms were analyzed. The variables for DEA model include one output and five inputs: fertilizer cost, harvesting cost, transportation & fuel cost, hired labor cost, other input cost and fresh fruit bunch output.

Table 4.1 present the descriptive statistics of variables related to RSPO oil palm farms. The average yield of oil palm plantation is 21.11 ton per hectare. It is higher than an average oil palm yield of 19.54 ton per hectare in southern region as reported by agricultural statistics of Thailand book (2014) from Office of Agricultural Economics Thailand.

On average, the RSPO oil palm farmers spend 473.61 baht per ton of fresh fruit bunch on fertilizer, 390.79 baht per ton of fresh fruit bunch on harvesting, 190.51 baht per ton of fresh fruit bunch on transportation and fuel, 195.82 baht per ton of fresh fruit bunch on hired labor for fertilizer application, grass cutting, frond pruning, herbicide application and 40.73 baht per ton of fresh fruit bunch on other input costs including herbicide cost, fuel cost for grass cutting or others.

Table 4.1: Descriptive statistics of output and input variables

Variables	Unit	Mean	Minimum	Maximum	Std. Dev.
Fresh Fruit Bunch Production	Metric Tons/ha	21.11	6.38	52.77	9.25
Fertilizer Cost	Baht/Ton.FFB	473.61	0.00	1,525.08	295.24
Harvesting Cost	Baht/Ton.FFB	390.79	287.12	573.23	74.30
Transportation & Fuel Cost	Baht/Ton.FFB	190.51	21.97	554.14	77.80
Hired Labor Cost	Baht/Ton.FFB	195.82	0.00	681.83	168.72
Other Input Cost	Baht/Ton.FFB	40.73	0.00	402.29	80.93

4.2 Result of value-based efficiency model of Tone (2002):

The mean of value-based technical, value-based cost and value-based allocative efficiencies score for all RSPO oil palm farms was found to be 0.86038, 0.55080 and 0.63402. Value-based technical efficiency measure the relationship between input-spending in oil palm production process and fresh fruit bunch output. Value-based technical efficiency was found to be 0.86, on average. This imply that, on average, RSPO oil palm farms with in studied group could reduce their input-spending by 14 percent and still produce the same level of fresh fruit bunch output. Value-based cost efficiency measure as the ratio of the minimum cost to the actual cost, it was found to be 0.55, on average. This meaning that on average 45 percent higher cost than needed if all oil palm farms were operating on the cost efficiency frontier. Value-based allocative efficiency measure as the ratio of value-based cost efficiency to value-based technical efficiency. In other word, the oil palm farm ability to produce a given level of fresh fruit bunch using cost minimizing input ratios, it was found to be 0.63, on average. This meaning that on average, 37 percent oil palm inefficient at choosing an input bundle that is cost minimizing as summary statistic for value-based technical efficiency, value-based cost efficiency and value-based allocative efficiency score present in Table 4.2.

Table 4.2: Summary statistic for value-based technical efficiency, value-based cost efficiency and value-based allocative efficiency score for all RSPO oil palm farms

	Value-based TE Score	Value-based CE Score	Value-based AE Score
Mean	0.86038	0.55080	0.63402
Maximum	1.00000	1.00000	1.00000
Minimum	0.53004	0.25318	0.31431
Std. Dev.	0.12285	0.18664	0.16916

The frequency distribution of value-based technical efficiency, value-based cost efficiency and value-based allocative efficiency of RSPO oil palm farms is illustrated in Table 4.3, the average technical efficiency of RSPO oil palm farms ranged from minimum of 53.00 percent and a maximum of 100 percent with a mean of 86.04 percent. The result revealed that 15 farms out of 78 having technical efficiency score equal to one meaning that those farms are technically efficient. These represent 19.23 percent of RSPO oil palm farms operating on the technical efficiency frontier. Moreover, no oil palm farm has technical efficiency less than 50 percent, this meaning that RSPO oil palm farms in Thailand achieve high technical efficiency production. The result of this study revealed an average cost 55.08 percent, with a minimum of 25.32 percent and a maximum of 100 percent. Only two oil palm farms have cost efficiency score equal to 1. While, 35 oil palm farms amounting to 26 percent possess the lowest cost efficiency score of less than 50 percent. This revealed that RSPO oil palm farms in Thailand achieve low cost efficiency production. Furthermore, the average allocative efficiency of RSPO oil palm farms at 63.40 percent, with a minimum of 31.43 percent and a maximum of 100 percent.

Table 4.3: Frequency distribution of value-based technical efficiency, value-based cost efficiency and value-based allocative efficiency for RSPO oil palm farms

Efficiency Level	Value-based Technical, Cost and Allocative Efficiency					
	Value-based TE		Value-based CE		Value-based AE	
	Number of farm	%	Number of farm	%	Number of farm	%
0.01-0.10	0	0%	0	0%	0	0%
0.11-0.20	0	0%	0	0%	0	0%
0.21-0.30	0	0%	6	8%	0	0%
0.31-0.40	0	0%	11	14%	5	6%
0.41-0.50	0	0%	18	23%	17	22%
0.51-0.60	2	3%	17	22%	13	17%
0.61-0.70	9	12%	9	12%	16	21%
0.71-0.80	8	10%	8	10%	13	17%
0.81-0.90	28	36%	6	8%	8	10%
0.91-1.00	31	40%	3	4%	6	8%
Total	78	100%	78	100%	78	100%

4.3 Number of DMUs appeared in reference set in the basis of benchmarking cost efficiency

DMU 63 and DMU 70 achieved highest rank and operated their farms on the cost efficiency frontier. Oil palm farmer of DMU 63 operated 4 oil palm farm plots in the sample data. This oil palm farmer normally used natural fertilizer such as empty fresh fruit bunch together with chemical fertilizer. Oil palm farmer of DMU 70 operated 3 oil palm farm plots in the sample data. This oil palm farmer installed artesian well to their oil palm farm. In dry season, this oil palm farmer spent electricity cost to ensure oil palm trees has enough water-supply.

Table 4.4: Highest ranking of DMUs on the basis of cost efficiency

DMU	Technical Efficiency Score	Cost Efficiency Score	Allocative Efficiency Score	Frequency in reference set
63	1.00000	1.00000	1.00000	77
70	1.00000	1.00000	1.00000	14

4.4 Descriptive analysis of data used for regression model

The factors affecting RSPO oil palm cost efficiency were analyzed by using ordinary least square regression. After obtaining cost efficiency values from the value-based cost efficiency of Tone (2002) model, the value-based cost efficiency score were selected as the dependent variables and were regressed against explanatory variables as independent variables including gender of oil palm farmer, age, farm size, non-herbicide applied dummy, applied empty fresh fruit bunch dummy, age of oil palm from 3 to 8 years dummy, age of oil palm from 9 to 19 years dummy, paid for water-supply dummy, watercourse dummy, strength fertilizer dummy. The explanatory variables can be classified into four categories: demographic and farm management characteristics variables, age variables, location variables and fertilizer variable.

Table 4.5 present descriptive statistics of explanatory variables. The number of observation for each explanatory variable was 78 observations. The age ranged of RSPO oil palm farmer was between 28 to 80 years old, with the average 49 years old, while farm size ranging between 0.16 and 20.41**.** Gender, non-herbicide applied, applied empty fresh fruit bunch, age of oil palm 3 to 8 years, age of oil palm 9 to 19 years, paid for water-supply, watercourse, strength fertilizer are dummy variable with a minimum value of 0 and a maximum value of 1 with means of 0.68, 0.69, 0.08, 0.28, 0.64, 0.05, 0.36 and 0.83 respectively.

Table 4.5: Descriptive statistics of explanatory variables

Variables	Unit	Mean	Min	Max	S.D.
Gender	Dummy	0.68	0	1	-
Age	Year	48.51	28	80	10.98
Farm Size	Hectares	3.6	0.16	20.41	3.04
Non-herbicide applied	Dummy	0.69	0	1	-
Applied empty fresh fruit bunch	Dummy	0.08	0	1	-
Age of oil palm 3 to 8 years	Dummy	0.28	0	1	-
Age of oil palm 9 to 19 years	Dummy	0.64	0	1	-
Paid for water-supply	Dummy	0.05	0	1	-
Watercourse	Dummy	0.36	0	1	-
Strength fertilizer	Dummy	0.83	0	1	-

4.5 Results of ordinary least square regression analysis

The result of the ordinary least square was obtained using MINITAB 17 computer program. Following the empirical result from regression analysis, two important factors affecting an increase in cost efficiency of RSPO oil palm farm are applied empty fresh fruit bunch and paid for water-supply. Applied empty fresh fruit bunch and paid for water-supply show positive coefficient and are statistically related to efficiency indexes at one percent level of significance. This means that oil palm farmers who used empty fresh fruit bunch in oil palm plantation and paid for water-supply in dry season have higher cost efficiency than those without. Farm size show negative coefficient and are statistically related to efficiency indexes at one percent level of significance. This means that oil palm farmers who operated small plantation area have higher cost efficiency than large plantation area.

Following a variation in age of palm in sample data of RSPO oil palm farm, the age variables were used to emphasize the age of oil palm tree effect towards cost efficiency. The result revealed that age of oil palm in period of 3 to 8 years has negative coefficient and age of oil palm in period of 9 to 19 years has positive coefficient which corresponds with the nature of oil palm tree. The rapid-increase, yield-peak and decline periods of oil palm were reported in between 3-8 years, 9-19 years and over 20 years (Commodity Intelligence Report, 2012), respectively.

Location variables were introduced to investigate the effect of location of water-supply towards cost efficiency. The result showed that the paid for water-supply has positive coefficient as oil palm trees obtain water-supply in dry season.

Strength fertilizer was used to emphasize the effect towards cost efficiency. The result showed that strength fertilizer has positive coefficient.

Table 4.6: Result of ordinary least square regression analysis

Variables	Coefficient	Standard error	t-value	p-value
Constant	0.665	0.133	5.00	0.000
Gender	-0.0165	0.0442	-0.37	0.710
Age	-0.00112	0.00185	-0.60	0.548
Farm Size	-0.02044	0.00653	-3.13	0.003
Non-herbicide applied	-0.0444	0.0487	-0.91	0.365
Applied empty fresh fruit bunch	0.2608	0.0763	3.42	0.001
Age of oil palm 3 to 8 years	-0.0417	0.0781	-0.53	0.595
Age of oil palm 9 to 19 years	0.0107	0.0733	0.15	0.885
Paid for water-supply	0.2671	0.0956	2.79	0.007
Watercourse	-0.0531	0.0453	-1.17	0.245
Strength fertilizer	0.0550	0.0580	0.95	0.347

Chapter 5
Conclusion and Recommendation

5.1 Conclusion

The purpose of this study was to measure technical, cost, allocative efficiencies and to find out factors affecting cost efficiency of RSPO oil palm as well as to focus on the impact of sustainable oil palm plantation. Data were collected from 116 oil palm farms from 66 smallholder farmers of RSPO oil palm farms; data from 78 oil palm farms were analyzed. This study adopted data envelopment analysis method in technical, cost and allocative efficiencies model of Tone (2002) to measure efficiency and used ordinary least square regression to find factors affecting cost efficiency. The efficiency analysis estimated technical, cost and allocative efficiency level to be 86.04%, 55.08% and 63.40%, respectively.

The output and input variables used in this study included fertilizer cost, hired labor cost, transportation & fuel cost, harvesting cost and other input cost as inputs in addition to fresh fruit bunch production as output. These output and input variables were used in the first stage of DEA analysis to obtain technical, cost and allocative efficiency scores of RSPO oil palm farms under variable return to scale assumption. Then, the cost efficiency score obtained from the first stage were used as independent variable to explore the factors affecting cost efficiency of these RSPO oil palm farms through the ordinary least square model for regression analysis.

Demographic and farm management characteristics variables, age variables, location variables and fertilizer variable were used to investigate efficiency determinants. The regression model showed that applied empty fresh fruit bunch, age of oil palm from 9 to 19 years, paid for water supply and strength fertilizer positively influenced cost efficiency. While, gender, age, farm size, non-herbicide applied, age of oil palm from 3 to 8 years, watercourse presented negative relationship with cost efficiency. Most of the explanatory variables in efficiency model revealed the results with expected sign of coefficient.

From the empirical result of regression analysis, among the factors which were investigated for their effect on cost efficiency, the study revealed that two important factors affecting an increase in cost efficiency of RSPO oil palm farm are applied empty fresh fruit bunch and paid for water-supply. These variables were found to be significant and showed positive relationship with cost efficiency. The results of this study implied that the sustainable oil palm plantation helps enhancing cost efficiency level in Thai oil palm industry.

5.2 Recommendation for further study

This study can be improved in a number of areas. These include employing fractional regression model in the second stage of DEA to explore factors affecting efficiency as well as executing DEA and stochastic frontier analysis then comparing the results.

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Appendices

Appendix A

Raw Data of Inputs and Output for DEA

DMU	Fresh Fruit Bunch Production	Fertilizer Cost	Harvesting Cost	Transportation & Fuel Cost	Hired Labor Cost	Other Input Cost
1	25.82	432.62	369.19	157.65	101.55	34.10
2	20.22	423.70	400.00	200.00	221.49	162.71
3	20.26	385.54	290.92	123.42	0.00	0.00
4	16.08	298.50	573.23	226.75	245.16	0.00
5	10.57	1,070.23	431.51	203.14	177.05	110.99
6	23.61	513.27	409.96	204.63	88.06	62.90
7	23.96	783.80	410.70	204.86	181.40	61.61
8	8.75	552.86	350.04	200.00	0.00	100.00
9	17.11	366.13	350.02	200.00	0.00	26.49
10	18.97	740.01	350.24	44.14	206.70	0.00
11	21.49	275.78	331.95	204.51	195.23	0.00
12	23.70	292.11	340.93	192.35	146.83	0.00
13	16.55	389.67	349.81	164.21	461.03	0.00
14	13.53	345.77	426.41	258.06	306.47	0.00
15	21.92	568.21	303.30	303.30	244.49	13.87
16	12.90	928.04	300.00	300.00	365.31	0.00
17	20.68	420.47	445.92	105.21	84.62	0.00
18	14.56	663.20	400.00	200.00	570.07	5.37
19	12.75	752.67	400.00	200.00	633.73	0.00
20	11.98	707.82	554.14	554.14	681.83	0.00
21	13.26	394.03	329.50	242.46	336.90	0.00

DMU	Fresh Fruit Bunch Production	Fertilizer Cost	Harvesting Cost	Transportation & Fuel Cost	Hired Labor Cost	Other Input Cost
22	22.79	365.57	361.27	218.03	209.08	0.00
23	23.04	379.70	349.89	216.70	209.96	0.00
24	32.45	235.18	384.40	289.51	132.54	0.00
25	10.61	1,321.16	449.47	202.31	360.89	0.00
26	14.97	363.27	349.94	92.76	375.23	0.00
27	39.15	167.00	349.89	67.22	166.11	0.00
28	13.67	640.52	355.92	202.54	304.34	2.83
29	20.07	357.33	350.00	200.00	143.15	12.89
30	14.91	639.32	332.20	332.20	0.00	221.00
31	10.22	888.44	294.54	196.55	357.57	0.00
32	10.71	395.60	359.96	105.63	643.41	0.00
33	13.33	503.70	350.63	106.32	584.97	0.00
34	23.02	275.26	346.06	213.89	81.84	0.00
35	32.98	449.89	450.00	200.00	96.06	302.92
36	21.33	0.00	383.70	237.04	46.06	54.19
37	18.96	479.38	446.28	53.92	241.95	0.00
38	47.22	203.58	349.96	241.22	73.53	0.00
39	23.10	335.48	396.39	113.07	152.68	0.00
40	12.11	347.69	344.23	182.90	325.21	0.00
41	11.05	1,065.50	359.92	299.98	294.54	268.82
42	23.38	875.69	299.51	250.28	129.02	0.00
43	13.21	839.45	357.22	215.07	0.00	16.55
44	33.31	180.55	349.63	193.41	0.00	6.57
45	15.42	286.77	548.99	199.62	253.44	0.00
46	17.33	280.62	549.28	199.71	102.10	0.00

DMU	Fresh Fruit Bunch Production	Fertilizer Cost	Harvesting Cost	Transportation & Fuel Cost	Hired Labor Cost	Other Input Cost
47	25.82	219.78	566.14	200.35	86.53	0.00
48	6.38	555.71	550.55	199.32	578.72	0.00
49	29.32	190.35	548.08	199.55	159.16	0.00
50	15.02	325.47	547.48	198.72	139.98	0.00
51	23.72	293.25	550.06	200.00	123.75	0.00
52	18.78	884.42	450.00	200.00	461.32	146.31
53	26.65	772.12	450.00	200.00	367.51	163.08
54	21.42	671.72	450.16	200.07	411.43	149.11
55	22.44	368.27	344.39	198.52	116.31	0.00
56	15.35	448.10	347.27	227.01	185.82	0.00
57	29.40	261.50	348.08	207.81	86.62	10.42
58	37.38	201.02	335.53	200.00	65.63	8.20
59	41.43	173.99	334.01	193.26	59.12	7.40
60	32.99	672.38	350.00	200.00	101.28	303.85
61	19.51	990.26	350.00	198.48	147.05	402.29
62	27.27	218.84	398.37	26.54	201.36	2.33
63	26.77	212.65	355.70	29.83	26.46	7.78
64	23.30	271.70	351.48	21.97	32.76	9.19
65	15.68	380.88	376.15	42.51	47.31	8.23
66	21.45	163.78	420.49	198.82	24.95	21.09
67	24.10	235.67	397.73	198.87	24.60	15.54
68	13.12	150.48	397.80	198.41	26.87	23.45
69	38.13	94.94	330.00	202.48	59.14	42.58
70	52.77	41.20	322.28	221.37	37.84	31.62
71	18.59	559.11	287.12	220.68	156.28	117.88

DMU	Fresh Fruit Bunch Production	Fertilizer Cost	Harvesting Cost	Transportation & Fuel Cost	Hired Labor Cost	Other Input Cost
72	16.63	140.64	350.69	249.47	0.00	29.10
73	18.51	507.70	341.75	193.89	128.70	16.36
74	17.75	359.30	348.05	200.86	98.24	28.84
75	12.65	871.98	347.59	198.66	180.19	58.70
76	6.84	1,525.08	348.89	198.94	250.60	103.10
77	17.82	260.31	500.00	63.78	251.60	0.00
78	42.35	737.72	498.90	50.71	105.11	6.69

Appendix B

Value-based Technical Score, Value-based Cost Score and Value-based Allocative Efficiency Score for Each RSPO Oil Palm Farm in the Sample

DMU	Value-based Technical Efficiency Score	Value-based Cost Efficiency Score	Value-based Allocative Efficiency Score
1	0.814092	0.57750	0.70938
2	0.743367	0.44920	0.60428
3	1	0.79066	0.79066
4	0.605774	0.47069	0.77700
5	0.672982	0.31734	0.47154
6	0.716903	0.49454	0.68983
7	0.716419	0.38507	0.53750
8	0.831115	0.52576	0.63260
9	0.876267	0.67092	0.76565
10	1	0.47159	0.47159
11	0.971923	0.62775	0.64588
12	0.940923	0.65051	0.69135
13	0.868108	0.46341	0.53382
14	0.759952	0.47313	0.62258
15	0.96375	0.44128	0.45788
16	0.969733	0.33403	0.34445
17	0.91112	0.59878	0.65719
18	0.726985	0.34397	0.47315
19	0.727299	0.31838	0.43776
20	0.530044	0.25318	0.47767
21	0.906226	0.48541	0.53564
22	0.858747	0.54806	0.63821
23	0.873128	0.54697	0.62645

DMU	Value-based Technical Efficiency Score	Value-based Cost Efficiency Score	Value-based Allocative Efficiency Score
24	0.887597	0.61175	0.68922
25	0.647248	0.27099	0.41867
26	0.932163	0.53542	0.57438
27	1	0.85689	0.85689
28	0.817171	0.41990	0.51385
29	0.852273	0.59475	0.69784
30	0.875734	0.41479	0.47365
31	0.987697	0.36408	0.36861
32	0.886807	0.42033	0.47398
33	0.895969	0.40918	0.45669
34	0.946059	0.68964	0.72896
35	0.692377	0.42542	0.61444
36	1	0.87716	0.87716
37	1	0.51774	0.51774
38	1	0.74818	0.74818
39	0.815646	0.63395	0.77724
40	0.901609	0.50721	0.56256
41	0.797714	0.27632	0.34639
42	0.994108	0.40684	0.40925
43	0.814389	0.44279	0.54371
44	1	0.87369	0.87369
45	0.630541	0.49071	0.77823
46	0.827679	0.55883	0.67518
47	0.975526	0.58952	0.60431
48	0.563819	0.33564	0.59529
49	0.918622	0.57839	0.62963
50	0.699415	0.52196	0.74628
51	0.764747	0.54190	0.70860
52	0.645986	0.29525	0.45705

DMU	Value-based Technical Efficiency Score	Value-based Cost Efficiency Score	Value-based Allocative Efficiency Score
53	0.66755	0.32388	0.48517
54	0.64861	0.33596	0.51796
55	0.890008	0.61552	0.69159
56	0.843592	0.52345	0.62050
57	0.899804	0.69404	0.77132
58	0.973915	0.79143	0.81263
59	1	0.83979	0.83979
60	0.86559	0.39181	0.45265
61	0.826658	0.30288	0.36639
62	1	0.74679	0.74679
63	1	1.00000	1.00000
64	1	0.92043	0.92043
65	0.908869	0.73962	0.81378
66	0.827284	0.76276	0.92201
67	0.819623	0.72492	0.88446
68	0.849724	0.79350	0.93383
69	0.972413	0.88049	0.90546
70	1	1.00000	1.00000
71	1	0.47159	0.47159
72	1	0.82145	0.82145
73	0.849956	0.53217	0.62612
74	0.856232	0.61088	0.71345
75	0.832429	0.38164	0.45847
76	0.829184	0.26062	0.31431
77	0.992832	0.58794	0.59218
78	1	0.46139	0.46139

Appendix C

Optimal Input Spending for Each RSPO Oil Palm Farm in the Sample to Reach Cost Efficiency Frontier

DMU	Fertilizer Cost	Harvesting Cost	Transportation & Fuel Cost	Hired Labor Cost	Other Input Cost
1	212.65	355.7	29.834	26.462	7.7828
2	212.65	355.7	29.834	26.462	7.7828
3	212.65	355.7	29.834	26.462	7.7828
4	212.65	355.7	29.834	26.462	7.7828
5	212.65	355.7	29.834	26.462	7.7828
6	212.65	355.7	29.834	26.462	7.7828
7	212.65	355.7	29.834	26.462	7.7828
8	212.65	355.7	29.834	26.462	7.7828
9	212.65	355.7	29.834	26.462	7.7828
10	212.65	355.7	29.834	26.462	7.7828
11	212.65	355.7	29.834	26.462	7.7828
12	212.65	355.7	29.834	26.462	7.7828
13	212.65	355.7	29.834	26.462	7.7828
14	212.65	355.7	29.834	26.462	7.7828
15	212.65	355.7	29.834	26.462	7.7828
16	212.65	355.7	29.834	26.462	7.7828
17	212.65	355.7	29.834	26.462	7.7828
18	212.65	355.7	29.834	26.462	7.7828
19	212.65	355.7	29.834	26.462	7.7828
20	212.65	355.7	29.834	26.462	7.7828
21	212.65	355.7	29.834	26.462	7.7828
22	212.65	355.7	29.834	26.462	7.7828
23	212.65	355.7	29.834	26.462	7.7828
24	175.15	348.39	71.723	28.951	12.995

DMU	Fertilizer Cost	Harvesting Cost	Transportation & Fuel Cost	Hired Labor Cost	Other Input Cost
25	212.65	355.7	29.834	26.462	7.7828
26	212.65	355.7	29.834	26.462	7.7828
27	130.99	339.78	121.06	31.883	19.134
28	212.65	355.7	29.834	26.462	7.7828
29	212.65	355.7	29.834	26.462	7.7828
30	212.65	355.7	29.834	26.462	7.7828
31	212.65	355.7	29.834	26.462	7.7828
32	212.65	355.7	29.834	26.462	7.7828
33	212.65	355.7	29.834	26.462	7.7828
34	212.65	355.7	29.834	26.462	7.7828
35	171.71	347.72	75.573	29.18	13.474
36	212.65	355.7	29.834	26.462	7.7828
37	212.65	355.7	29.834	26.462	7.7828
38	77.78	329.41	180.5	35.416	26.531
39	212.65	355.7	29.834	26.462	7.7828
40	212.65	355.7	29.834	26.462	7.7828
41	212.65	355.7	29.834	26.462	7.7828
42	212.65	355.7	29.834	26.462	7.7828
43	212.65	355.7	29.834	26.462	7.7828
44	169.51	347.29	78.033	29.326	13.781
45	212.65	355.7	29.834	26.462	7.7828
46	212.65	355.7	29.834	26.462	7.7828
47	212.65	355.7	29.834	26.462	7.7828
48	212.65	355.7	29.834	26.462	7.7828
49	195.81	352.42	48.649	27.58	10.124
50	212.65	355.7	29.834	26.462	7.7828
51	212.65	355.7	29.834	26.462	7.7828
52	212.65	355.7	29.834	26.462	7.7828
53	212.65	355.7	29.834	26.462	7.7828

DMU	Fertilizer Cost	Harvesting Cost	Transportation & Fuel Cost	Hired Labor Cost	Other Input Cost
54	212.65	355.7	29.834	26.462	7.7828
55	212.65	355.7	29.834	26.462	7.7828
56	212.65	355.7	29.834	26.462	7.7828
57	195.29	352.32	49.227	27.614	10.196
58	142.7	342.06	107.98	31.106	17.507
59	115.96	336.85	137.84	32.881	21.223
60	171.63	347.71	75.659	29.185	13.485
61	212.65	355.7	29.834	26.462	7.7828
62	209.35	355.06	33.528	26.681	8.2425
63	212.65	355.7	29.834	26.462	7.7828
64	212.65	355.7	29.834	26.462	7.7828
65	212.65	355.7	29.834	26.462	7.7828
66	212.65	355.7	29.834	26.462	7.7828
67	212.65	355.7	29.834	26.462	7.7828
68	212.65	355.7	29.834	26.462	7.7828
69	137.7	341.09	113.56	31.438	18.202
70	41.198	322.28	221.37	37.844	31.617
71	212.65	355.7	29.834	26.462	7.7828
72	212.65	355.7	29.834	26.462	7.7828
73	212.65	355.7	29.834	26.462	7.7828
74	212.65	355.7	29.834	26.462	7.7828
75	212.65	355.7	29.834	26.462	7.7828
76	212.65	355.7	29.834	26.462	7.7828
77	212.65	355.7	29.834	26.462	7.7828
78	109.91	335.67	144.61	33.283	22.065

Appendix D

Optimal Input Spending for Each RSPO Oil Palm Farm in the Sample to Reach Technical Efficiency Frontier

DMU	Fertilizer Cost	Harvesting Cost	Transportation & Fuel Cost	Hired Labor Cost	Other Input Cost
1	324.65	300.56	128.34	21.58	3.49
2	314.96	297.35	143.50	7.76	6.48
3	385.54	290.92	123.42	0.00	0.00
4	180.82	347.25	88.78	148.51	0.00
5	409.26	290.40	136.71	21.36	16.11
6	367.97	293.90	145.33	22.15	17.04
7	364.83	294.23	146.77	23.15	17.83
8	385.54	290.92	123.42	0.00	0.00
9	320.83	306.71	156.73	0.00	7.69
10	740.01	350.24	44.14	206.70	0.00
11	268.04	322.63	93.20	89.31	0.00
12	274.86	320.79	94.95	84.13	0.00
13	338.27	303.67	111.26	35.93	0.00
14	262.77	324.05	91.85	93.32	0.00
15	383.30	292.30	138.48	17.50	13.37
16	385.54	290.92	123.42	0.00	0.00
17	383.10	316.07	95.86	77.10	0.00
18	391.29	290.79	126.64	5.17	3.90
19	385.54	290.92	123.42	0.00	0.00
20	375.17	293.72	120.75	7.88	0.00
21	357.08	298.60	116.10	21.63	0.00
22	313.93	310.24	105.00	54.43	0.00
23	331.53	305.50	109.53	41.06	0.00
24	208.75	341.19	120.46	117.65	0.00

DMU	Fertilizer Cost	Harvesting Cost	Transportation & Fuel Cost	Hired Labor Cost	Other Input Cost
25	385.54	290.92	123.42	0.00	0.00
26	338.62	326.20	86.47	105.17	0.00
27	167.00	349.89	67.22	166.11	0.00
28	388.95	290.85	125.33	3.07	2.31
29	304.54	298.30	146.46	8.90	7.44
30	385.54	290.92	123.42	0.00	0.00
31	385.54	290.92	123.42	0.00	0.00
32	350.82	319.21	93.68	84.54	0.00
33	451.30	314.16	95.26	75.93	0.00
34	260.42	327.40	136.17	77.42	0.00
35	247.02	311.57	138.48	44.45	8.59
36	0.00	383.70	237.04	46.06	54.19
37	479.38	446.28	53.92	241.95	0.00
38	203.58	349.96	241.22	73.53	0.00
39	273.63	323.32	92.22	91.81	0.00
40	313.48	310.36	104.89	54.77	0.00
41	559.11	287.12	220.68	156.28	117.88
42	364.49	297.75	137.05	8.51	0.00
43	385.54	290.92	123.42	0.00	0.00
44	180.55	349.63	193.41	0.00	6.57
45	180.82	346.16	70.77	155.60	0.00
46	232.26	337.19	165.30	84.51	0.00
47	214.40	344.10	195.44	84.41	0.00
48	313.32	310.41	104.85	54.89	0.00
49	174.86	349.91	104.62	146.21	0.00
50	227.64	336.92	138.99	97.91	0.00
51	224.27	338.72	152.95	94.64	0.00
52	395.85	290.69	129.20	9.28	7.00
53	316.29	300.40	133.51	19.15	4.73

DMU	Fertilizer Cost	Harvesting Cost	Transportation & Fuel Cost	Hired Labor Cost	Other Input Cost
54	377.55	291.98	129.77	5.75	4.45
55	327.76	306.51	108.56	43.92	0.00
56	378.02	292.95	121.48	5.72	0.00
57	235.30	313.20	140.10	47.78	9.38
58	195.77	326.77	160.60	63.92	7.99
59	173.99	334.01	193.26	59.12	7.40
60	267.97	302.96	173.12	32.36	25.63
61	458.09	289.33	164.07	65.32	49.27
62	218.84	398.37	26.54	201.36	2.33
63	212.65	355.70	29.83	26.46	7.78
64	271.70	351.48	21.97	32.76	9.19
65	302.85	341.87	38.64	32.46	7.48
66	135.49	345.62	164.48	20.64	17.45
67	193.16	325.99	163.00	20.17	12.74
68	127.87	338.02	168.60	22.83	17.97
69	92.32	320.90	196.89	44.15	25.24
70	41.20	322.28	221.37	37.84	31.62
71	559.11	287.12	220.68	156.28	117.88
72	140.64	350.69	249.47	0.00	29.10
73	406.02	290.47	134.89	18.43	13.91
74	307.64	298.01	145.58	8.56	7.15
75	457.49	289.34	163.74	64.78	48.87
76	459.67	289.30	164.96	66.74	50.35
77	258.44	378.10	63.32	188.31	0.00
78	737.72	498.90	50.71	105.11	6.69

Appendix E

Benchmarking of Inefficient Farms (Technical Efficiency)

DMU	Benchmark (Lambda)	Peer Group
1	3(0.784884); 27(0.104774); 70(0.110342)	3,27,70
2	3(0.795032); 70(0.204968)	3,70
3	3(1.000000)	3
4	3(0.044948); 27(0.845631); 38(0.109421)	3,27,38
5	3(0.863333); 71(0.136667)	3,71
6	3(0.775535); 70(0.109161); 71(0.115304)	3,70,71
7	3(0.760816); 70(0.120149); 71(0.119034)	3,70,71
8	3(1.000000)	3
9	3(0.735755); 72(0.264245)	3,72
10	10(1.000000)	10
11	3(0.462338); 27(0.537662)	3,27
12	3(0.493534); 27(0.506466)	3,27
13	3(0.783714); 27(0.216286)	3,27
14	3(0.438212); 27(0.561788)	3,27
15	3(0.845529); 70(0.056090); 71(0.098381)	3,70,71
16	3(1.000000)	3
17	3(0.574475); 10(0.158029); 27(0.267496)	3,10,27
18	3(0.966911); 71(0.033089)	3,71
19	3(1.000000)	3
20	3(0.952558); 27(0.047442)	3,27
21	3(0.869760); 27(0.130240)	3,27
22	3(0.672322); 27(0.327678)	3,27
23	3(0.752833); 27(0.247167)	3,27
24	3(0.147797); 27(0.593929); 38(0.258274)	3,27,38
25	3(1.000000)	3

DMU	Benchmark (Lambda)	Peer Group
26	3(0.402541); 10(0.145986); 27(0.451472)	3,10,27
27	27(1.000000)	27
28	3(0.980374); 71(0.019626)	3,71
29	3(0.764768); 70(0.235232)	3,70
30	3(1.000000)	3
31	3(1.000000)	3
32	3(0.520915); 10(0.122134); 27(0.356951)	3,10,27
33	3(0.607531); 10(0.264439); 27(0.128030)	3,10,27
34	3(0.381763); 27(0.345252); 38(0.272985)	3,27,38
35	3(0.522576); 27(0.205685); 70(0.271739)	3,27,70
36	36(1.000000)	36
37	37(1.000000)	37
38	38(1.000000)	38
39	3(0.450722); 10(0.014186); 27(0.535092)	3,10,27
40	3(0.670283); 27(0.329717)	3,27
41	71(1.000000)	71
42	3(0.884312); 38(0.115688)	3,38
43	3(1.000000)	3
44	44(1.000000)	44
45	3(0.063242); 27(0.936758)	3,27
46	3(0.215964); 27(0.290130); 38(0.493906)	3,27,38
47	3(0.098921); 27(0.196124); 38(0.704954)	3,27,38
48	3(0.669524); 27(0.330476)	3,27
49	27(0.785069); 38(0.214931)	27,38
50	3(0.220356); 27(0.438338); 38(0.341306)	3,27,38
51	3(0.189840); 27(0.378777); 38(0.431384)	3,27,38
52	3(0.940605); 71(0.059395)	3,71
53	3(0.769230); 27(0.081176); 70(0.149594)	3,27,70
54	3(0.934985); 70(0.037218); 71(0.027797)	3,70,71

DMU	Benchmark (Lambda)	Peer Group
55	3(0.735621); 27(0.264379)	3,27
56	3(0.965560); 27(0.034440)	3,27
57	3(0.483274); 27(0.220090); 70(0.296637)	3,27,70
58	3(0.196684); 27(0.181335); 59(0.482241); 70(0.139741)	3,27,59,70
59	59(1.000000)	59
60	3(0.491821); 70(0.397323); 71(0.110855)	3,70,71
61	3(0.582036); 71(0.417964)	3,71
62	62(1.000000)	62
63	63(1.000000)	63
64	64(1.000000)	64
65	3(0.158114); 10(0.028075); 64(0.813811)	3,10,64
66	36(0.070410); 44(0.396123); 63(0.244942); 70(0.288525)	36,44,63,70
67	3(0.264641); 27(0.032390); 44(0.281520); 63(0.102267); 70(0.319182)	3,27,44,63,70
68	3(0.012297); 44(0.317295); 63(0.222921); 70(0.447487)	3,44,63,70
69	3(0.117798); 27(0.083926); 70(0.798275)	3,27,70
70	70(1.000000)	70
71	71(1.000000)	71
72	72(1.000000)	72
73	3(0.882044); 71(0.117956)	3,71
74	3(0.773778); 70(0.226222)	3,70
75	3(0.585476); 71(0.414524)	3,71
76	3(0.572921); 71(0.427079)	3,71
77	27(0.707280); 37(0.292720)	27,37
78	78(1.000000)	78

Appendix F

Benchmarking of Inefficient Farms (Cost Efficiency)

DMU	Benchmark (Lambda)	Peer Group
1	63(1.000000)	63
2	63(1.000000)	63
3	63(1.000000)	63
4	63(1.000000)	63
5	63(1.000000)	63
6	63(1.000000)	63
7	63(1.000000)	63
8	63(1.000000)	63
9	63(1.000000)	63
10	63(1.000000)	63
11	63(1.000000)	63
12	63(1.000000)	63
13	63(1.000000)	63
14	63(1.000000)	63
15	63(1.000000)	63
16	63(1.000000)	63
17	63(1.000000)	63
18	63(1.000000)	63
19	63(1.000000)	63
20	63(1.000000)	63
21	63(1.000000)	63
22	63(1.000000)	63
23	63(1.000000)	63
24	63(0.7813), 70(0.2187)	63,70
25	63(1.000000)	63

DMU	Benchmark (Lambda)	Peer Group
26	63(1.000000)	63
27	63(0.52373), 70(0.47627)	63,70
28	63(1.000000)	63
29	63(1.000000)	63
30	63(1.000000)	63
31	63(1.000000)	63
32	63(1.000000)	63
33	63(1.000000)	63
34	63(1.000000)	63
35	63(0.76119), 70(0.23881)	63,70
36	63(1.000000)	63
37	63(1.000000)	63
38	63(0.21337), 70(0.78663)	63,70
39	63(1.000000)	63
40	63(1.000000)	63
41	63(1.000000)	63
42	63(1.000000)	63
43	63(1.000000)	63
44	63(0.74835), 70(0.25165)	63,70
45	63(1.000000)	63
46	63(1.000000)	63
47	63(1.000000)	63
48	63(1.000000)	63
49	63(0.90176), 70(0.098236)	63,70
50	63(1.000000)	63
51	63(1.000000)	63
52	63(1.000000)	63
53	63(1.000000)	63
54	63(1.000000)	63
55	63(1.000000)	63

DMU	Benchmark (Lambda)	Peer Group
56	63(1.000000)	63
57	63(0.89875), 70(0.10125)	63,70
58	63(0.592), 70(0.408)	63,70
59	63(0.43607), 70(0.56393)	63,70
60	63(0.76075), 70(0.23925)	63,70
61	63(1.000000)	63
62	63(0.98071), 70(0.019286)	63,70
63	63(1.000000)	63
64	63(1.000000)	63
65	63(1.000000)	63
66	63(1.000000)	63
67	63(1.000000)	63
68	63(1.000000)	63
69	63(0.56284), 70(0.43716)	63,70
70	70(1.000000)	70
71	63(1.000000)	63
72	63(1.000000)	63
73	63(1.000000)	63
74	63(1.000000)	63
75	63(1.000000)	63
76	63(1.000000)	63
77	63(1.000000)	63
78	63(0.40075), 70(0.59925)	63,70

Appendix G

Program Source-Code

1. Technical efficiency score model (TE): The source code of the technical efficiency score model is divided into two sub-files which are model file and data file. The source code is as follows.

1.1 Model file

```
{int} m=...;
{int} s=...;
{int} J=...;
float x[m][J]=...;
float y[s][J]=...;
int o=...;
dvar float+ weight[J];
dvar float+ Efficiency;


minimize Efficiency;
subject to{
forall( i in m)
ct1:  sum (j in J)weight[j]*x[i][j]<=Efficiency*x[i][o];

forall( r in s)
  sum (j in J)weight[j]*y[r][j]>=y[r][o];

  sum (j in J)weight[j]==1;
                                    }
```

1.2 Data file

```
o=1;
s={1};

SheetConnection sheet("CostData.xlsx");
//s from SheetRead(sheet,"ResultDATA3!B1:B1");
J from SheetRead(sheet,"3!A2:A79");
m from SheetRead(sheet,"3!C1:G1");
x from SheetRead(sheet,"3!C2:G79");
y from SheetRead(sheet,"3!B2:B79");
```

2. Cost efficiency score model: The source code of the cost efficiency score (CE) is as follows.

2.1 Model file

```
{int} m=...;
{int} s=...;
{int} J=...;
float x[m][J]=...;
float y[s][J]=...;
int o=...;
dvar float+ expenditure[m];
dvar float+ weight[J];


minimize (sum(i in m) expenditure[i])/(sum( i in m)x[i][o]);
subject to{
forall( i in m)
  sum (j in J)weight[j]*x[i][j]<=expenditure[i];

forall( r in s)
  sum (j in J)weight[j]*y[r][j]>=y[r][o];

  sum (j in J)weight[j]==1;
}
```

2.2 Data file

```
o=1;
s={1};

SheetConnection sheet("CostData.xlsx");
//s from SheetRead(sheet,"ResultDATA3!B1:B1");
J from SheetRead(sheet,"3!A2:A79");
m from SheetRead(sheet,"3!C1:G1");
x from SheetRead(sheet,"3!C2:G79");
y from SheetRead(sheet,"3!B2:B79");
```