System Dynamics Sustainability Model of Palm-Oil Based Biodiesel Production Chain in Indonesia

Akhmad Hidayatno[1,2], Aziiz Sutrisno[2], Yuri M. Zagloel[2], Widodo W. Purwanto[1]
[1] Chemical Engineering Department, Faculty of Engineering, Universitas Indonesia, Kampus UI Depok 16424, Indonesia
[2] Industrial Engineering Department, Faculty of Engineering, Universitas Indonesia, Kampus UI Depok 16424, Indonesia
e-mail: akhmad@eng.ui.ac.id

The nature of biodiesel production itself is complex with multi-sectors and multi-actors conditions, and with addition of sustainability issues from various stakeholder, created a complex challenges for developing the biodiesel industry. In order to understand of the complexity, this research developed a comprehensive sustainability model to draw the relationships and analyze the effects of government policy for stimulating biodiesel industry using the combination methods of process mapping, financial modeling, life cycle analysis (LCA) and business sustainability strategy. The model combines its output translated into a complete sustainability index of financial, social and environment. The model simulation results show that accomplishment of a sustainable biodiesel production within the target and timeframe is impossible without releasing the subsidized price of diesel fuel and further directions from the government.

***Index Terms*— biodiesel, system dynamics, sustainability**

I. Introduction

In Indonesia, oil still the major player for fulfilling the energy needs in the electricity generators, transportation, industrial, and household sectors. Unfortunately, the soaring oil consumption is negatively in line with the diminishing fossil energy resources. Responding to this issue, Indonesia's Government directed their focus on renewable energy, with the main highlight on biofuel. In 2006, the Indonesian government set its very first biofuel national policy as part of the efforts to ensure the fuel supply availability, from revising the national energy bill, creating mandatory markets, creating alternative fuel distribution policy, and plan to directly subsidized biodiesel price [1]. The objective of this biofuel development, besides to reduce imported oils and fuel subsidies, is to create employment (especially in rural areas) and to strengthen the agricultural sector, as well as to discover new export opportunities [2]. Early government plan estimates that biofuel will cover 10 percent of total fuel consumption for transportation sector and creates thousands of employment opportunities in 2010, and gradually increase into 20% in 2025 with total estimated demand is 10.22 million kl. The government published a national blueprint and roadmap 2006-2025 as a reference for all stakeholders in accomplishing the biofuel development objectives.

Indonesia is the largest palm oil producer in the world and also the second largest palm oil exporter in the world (after Malaysia) [3, 4], with estimated in 2009, a total 19.5 million tons of Crude Palm Oil (CPO) production, from a total area of land 7.31 ha [5]. With the maturity of the palm oil industry and the total availability land for agriculture production expansion of 46.9 million ha, palm-oil-based biodiesel is has a strong prospect to be developed. Biodiesel for palm oil has relatively low production cost and has equal performance compared with diesel fuel properties, therefore engine modification is relatively minimum [6, 7]. Biodiesel also does not require a major change in the fuel distribution infrastructure, which is a huge advantage for a big archipelago nation like Indonesia.

Despite the government efforts, the trend is not promising. It was estimated that in late 2008, there were 11 biodiesel producers, with total capacity of 1.6 million tones [8]. Many producers are previously CPO producers who would like to capitalize the new market, diversifying their old market, especially with the fluctuations of world CPO Prices in the 2008. However, in late 2009, the US Department of Agriculture's Foreign Agriculture Services reported that only 1 producers left with producing only 50% of its original capacity [9]. The producers blame government inconsistencies, un-attractive cost structure due to end price of diesel fuel, environmental pressure and social issues as the reasons for abandoning the business [10]. It shows how the fragmented ownership along the production chain is more difficult than single ownership of the oil industry, with private sectors owned more than half of palm oil industry demanding more support from the government.

Other nations in Asia that has strong palm oil industry, such as Thailand and Malaysia, also pursuing to develop a biodiesel industry from the palm oil [11, 12]. Of course, similar with Indonesia, the biodiesel industry development is still in the infant stage, with more research is needed to understand the complexity of developing this industry. These complexity arise from the sustainability challenges face by the development of biodiesel [10, 13], from the financial feasibility of producing biodiesel, the social impact of creating more jobs in the rural areas and quality of human resources surrounding the plantation, and the environment impact of losing forest land [14] .

This paper aims to provide an overview of the sustainability relationships between aspects of sustainability by using the a system dynamic sustainability model of biodiesel production chain, as a tool for better understanding the relationships between three aspects of sustainability and experimenting various policy planned by the government. Next step on the research is evaluation on whether the current policy would create an attractive condition for the biodiesel production.

IJENS

II. METHODOLOGY

The development of the model follows the four main stages of a generic system dynamics model development: model conceptualization, model formulation, model validation and model use through different scenarios [15]. The model conceptualization started with a construction of system diagram of problem statement, shown in Figure 1.

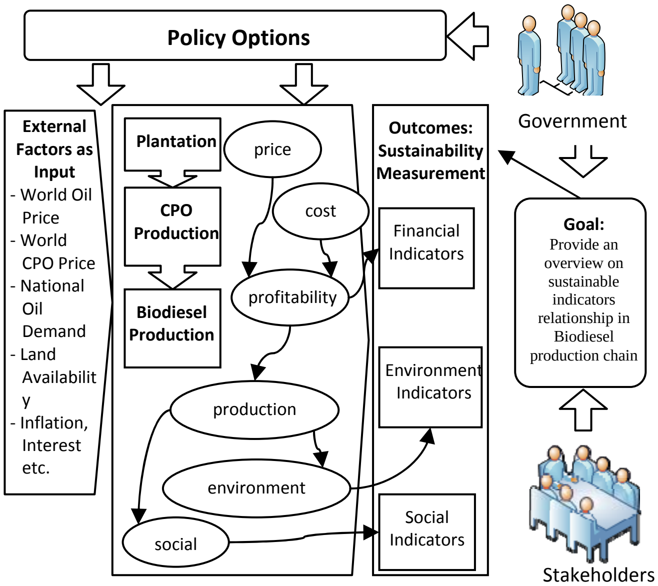

Fig. 1 System Diagram of the Problem Statement that Focused on Government as the Problem Owner

A system diagram of the problem statement consists of input, process, output and feedback diagram representation of the problem. In the modeling process, the diagram is used to define the problem more clearly and preliminary identification of variables and goals of the systems that must be supported by the model. The problem owner is government, which in this case, has the primary goal to meet the targeted biodiesel utilization. This goal must also align with other stakeholders who could affect the accomplishment of the goals, such as public, Non-Government Organizations and corporations; which create the three sustainability aspects from the systems: production target, LCA results and social indicators.

The biodiesel production chain simplifies into three stages, based on the possibility of independent ownership of each chain, form palm plantation, CPO production, and biodiesel production. Typically, there are two types of possible ownership structure of the industry: an integrated biodiesel production chain and independent biodiesel producers. The independent biodiesel producers do not have plantation land and must buy its feedstock from CPO producers. Reflecting on the systems diagram outcomes, the model assumed that the price would be the key factors on profitability of the industry, which in turn would affects the production volume of biodiesel and capacity expansion. The increased production should demand for more labor to support production, on the other hand would also increase the environmental impacts due to increased production. The external exogenous input variables are world oil and CPO price, national oil demand, land availability and economic indicators such as inflation and interest rate.

In the model formulation, the use of systems dynamics approach for the model is based on the need to be able to map the relationships and capture the behavior dynamics of the biodiesel industry. The model development started by creating a process map of the biodiesel production that includes the detailed cost calculations during the operational phase [16-21]. Assumptions in the model are: 10,000 ha plantation area with additional 2500 ha area from the independent local farmers' program, production capacity of 60,000 tons of biodiesel/year using trans-esterification process to produce biodiesel, and the extraction rate from Fresh Fruit Bunch (FFB) to CPO is 23.5% and extraction rate from CPO to biodiesel is 80%[16].

The cost model expanded into business financial model to calculate the financial indicators based on the process map. The calculation of the financial indicators of the model relied on a simple cash flow analysis focusing on earnings before interest, tax, depreciation and amortization (EBITDA).

The financial model added environment indicators by using a simple Life Cycle Analysis (LCA) calculation. ISO 14040:2006 standards define LCA as the collection and evaluation of input and output and the potential environment impact of a system life-cycle product [22, 23]. The environment LCA calculation used secondary data sources, starting from plantation (including land clearing) [16, 24-27], CPO production through CPO factory [16, 24, 27], and biodiesel factory [24].

Finally, all indicators were linked together with additional social aspects by studying how corporations measure sustainability of their enterprise [28-30]. For the calculation of the social indicators, the model assumed that the average workers the industry are 1000 workers per plantation [16].

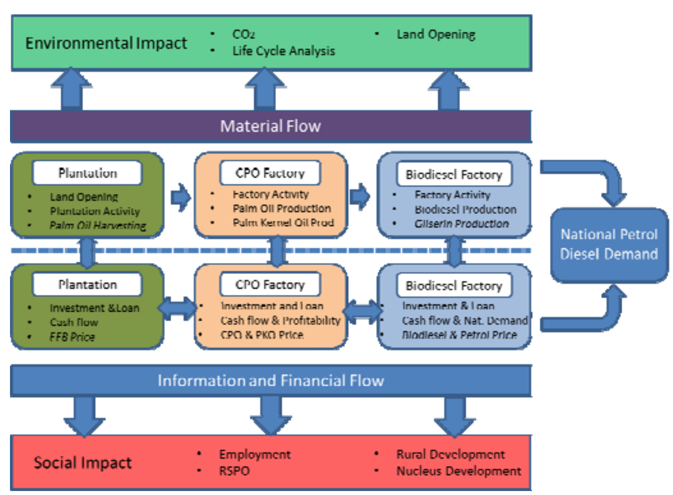

Fig. 2 Overview of the Conceptual Model Structure, with three production chain modules, demand modules and sustainability measurement module

The final sustainability model has all the three aspects of sustainability: financial, environment and social indicators, listed in Table 1. Using a system dynamics software, the model structure consists of three production chain major modules (plantation, CPO production, biodiesel production) and 2 supplementary modules (national biodiesel demand and sustainability indicators), shown in Figure 1. For each of the production chain modules, consist two sub-modules group: production and financial sub-modules.

TABLE 1
SELECTED INDICATORS OF SUSTAINABILITY

Indicator Group	Indicators	Unit
Economic	Biodiesel EBITDA	IDR
	Palm Oil Plantation EBITDA	IDR
	Biodiesel IRR	Percentage
Social	Number of Workers	People
	Number of Plasma Farmers	
	Household	Household Number
Environment	CO_2 Emission	kg CO_2
	Climate Change Impact	kiloTon Emision

Model verification and validation conducted by comparing simulation results with various historical data, and continued with supplemental validation tests, such as: checking adequacy of limits test, structure assessment test, extreme conditions test, integration error test, reproductive behavior test, and sensitivity analysis [31]. The key results such as CPO Productivity (ton/ha/year) has around 4% deviation [32] and FFB Productivity (ton/ha/year) has around 5% deviation [33].

III. MODEL DYNAMICS AND POLICY ANALYSIS

The model focuses on four key indicators for analysis: EBITDA, biodiesel production, employment and CO_2 emission. The four indicators have different units of measurement; therefore, these units was translated into index numbers by dividing each year output with 2010 outputs as the base year for comparison purpose.

At first the model simulated the current conditions of biodiesel policy to find the business as usual scenario, however the model preliminary results had shown that the biodiesel producers would not be able to achieve a positive cash flow and they would stop producing or investing. Without production, there is no emission or employment. Consequently, a feasible "business as usual" scenario is not available.

Instead, the model focused on a unique certain conditions existed in 2008, which made biodiesel production is attractive: a gap between high national oil price and low CPO price. This gap created a profitable margin for the biodiesel producers and attracted private investment. Recreating this condition, the model assumed that due to fiscal pressure on fuel subsidy with the increasing price of world oil, the government would release the diesel price to the market, and analyze if this could attractive enough to push biodiesel production. The model used the data and projections of world oil price from International Energy Agency (IEA) [34] and CPO world price from FAPRI for calculating the national oil price and biodiesel production cost.

A. *Sustainability Effects of Different Ownership Structure*

One critical characteristics that must be consider by the policy makers is the difference structure of ownerships which would affect not just the cost of producing biodiesel, but also the whole sustainability issues of biodiesel production. There is a notable difference of dynamics between two major types of ownerships structure: independent and integrated biodiesel producers. An independent producers must purchase CPO as raw material directly using market price. An integrated producers has its own plantation area, and can purchase CPO at the production cost price. An integrated producers must wait for 3-5 years before their plantation could produce an optimum level of CPO volume.

Figure 3 shows the behavior of an independent producer that is similar of a typical manufacturing company, in which the EBITDA and CO2 emission growth is in line with the growth of production volume and the employment is relatively stable after its reach the optimum level of production.

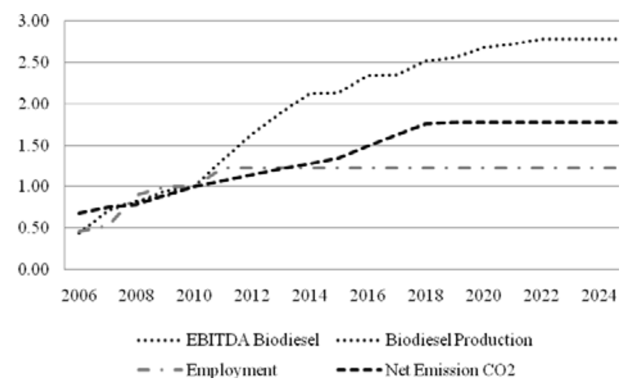

Fig. 3 Sustainability Index Behavior for Independent Biodiesel Ownership Structure

In the integrated producers, the palm plantation chain is dominating the dynamics of the whole chain, followed by CPO factory chain, and then the biodiesel chain (Figure 4). It shows the sustainability burden and contributions of maintaining the plantation land.

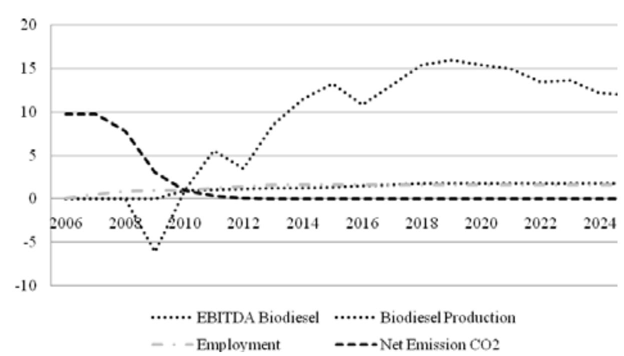

Fig. 4 Sustainability Index Behavior for Integrated Biodiesel Ownership Structure

Assuming that they have planned the production for 2010 starting by land preparation in 2006, the model shows that their EBITDA has higher index due to ability to purchase CPO at production cost, not based on market price. On the environment side, land preparation or clearing has the highest contribution of CO_2 emission. However, when the plantation has matured, it actually absorbs CO_2. Of course, cumulatively during the course of the simulation time (2006-2025), it still not compensate the lost of CO_2 absorption capacity of land conversion. Especially if the land is taken from forest land [35]. On employment, the plantation chain is dominating the impact with high demands of labor capital for development and maintenance of the plantation.

B. Policy Scenarios and Analysis

There are some policy options directly affecting the operations of biodiesel industry that within the government control. There are two simple categories of affecting factors: cost or revenue. In the revenue category, the government would release the currently subsidized price of diesel to the market price. This "No Fuel Subsidy" scenario would be analyzing the attractiveness for producing biodiesel. Based on the results of different ownership structure, the most feasible option is an integrated biodiesel producers.

In the cost category are operational cost and financial cost. The operational cost along with the CPO cost (raw material cost) is the dominant factor of overall biodiesel cost, the model shows that with 2008 prices, the cost of CPO as raw material is already at more than 62% of the production cost, and will be increasing. The financial cost are capital loan interest rate, loan grace period, loan repayment period, bank credits to nucleolus farmers that must be guaranteed by the producer, income taxes, value added tax, export tax, and export administration cost. In the revenue category are national fuel price and production incentive, with the current production incentive of 2,000 IDR/liter (0.25 USD/liter) is already in place this year. A "tax and interest" scenario is a scenario that focuses on the reduction of income tax rate and interest rate based on the cost structure of the producer. Table 2 shows the difference of variables for each scenario, including the current condition (Business as Usual)

TABLE 2
SCENARIO VARIABLES

Model Variables	1. Business as Usual	2. No Fuel Subsidy	3. Tax & Interest Holiday
Production Incentive	2000 IDR/liter	-	-
Income Tax	30%	30%	10%
Interest Rate	15%	15%	5%
Grace Period	10 years	10 years	10 years
Biodiesel Price	Subsidized	Market Price	Subsidized

Table 3 shows the results of scenarios. The first scenario, Business as Usual, shows the unattractiveness of the current conditions for the biodiesel producers, which explains why after a quick growth of producers in 2008, and followed by a rapid decline in 2010. The second scenarios, the release of fuel price, resulted in favorable condition in 2025, which the whole production capacity of the biodiesel production is in use. This would employ more workers; however, on the other hand, the full capacity of production would create higher CO2 emission.

The third scenario, tax and interest support, even though shows a promising results of biodiesel production, the conditions is still not attractive enough to drive capacity expansion. The model has a feedback mechanism that evaluates the increase profitability of producer to the cost of expansion; if this is not attractive then the producer will halt the expansion. As detailed on the figure 4, the EBITDA behavior of the third scenario is positive but not high enough to justify expansion decision comparing to the second scenario.

TABLE 3
SCENARIO RESULTS (IN 2025)

Sustainability Indicators	1. Business as Usual	2. No Fuel Subsidy	3. Tax & Interest Holiday
Biodiesel Production (Ton)	-	60.000	39,473.68
EBITDA (IDR)	-	202.952.924.298	156.831.680.986
Employment (People)	-	600	390
Net CO_2 Emission (Ton)	-	101.415	48.380

Another insight that the research produce is change of land class will change the sustainability structure with higher land class: less operational cost to fund (better EBITDA), less production area to work on (better environment), however less workers to hire (less social impacts). Of course, higher land productivity usually comes in the expense of forestland conversion, hence reducing the amount of carbon emission absorption, oxygen production and biodiversity.

IV. CONCLUSION

The systems dynamic model of biodiesel production chain has been giving a better understanding of the development of biodiesel industry. The model could evaluate that current efforts of the government is still not creating an attractive investment climate for the biodiesel industry. Creating mandatory markets and production cost incentive is a good start, however for the long run; the best policy is to release the market price of diesel and creating a mechanism to maintain the price of CPO as the raw material for biodiesel.

As different ownership structure would produce a different behavior, independent biodiesel producers would not face challenge of sustainability aspects as high as an integrated biodiesel producer would. Their sustainability behavior is similar to manufacturing companies, which directly tied to the production volume. The best strategy to increase the sustainability indicators, they should focus more streamlining their operations for better efficiency and effectiveness.

In the integrated producer, sustainable development of biodiesel industry cannot be separated with the development of the sustainable palm oil industry, since it dominates the environmental and social aspects of the whole production chain. Government could create an incentive for palm oil producers to get environmental certifications and push them to develop a corporate social responsibility program to increase the sustainability values of biodiesel production.

The model is still a work in progress and would still have limitations, as in any other model. However, it is already prove its ability to deliver more understanding of sustainability issues in developing the industry. Further research could expand the sustainability impact analysis of the micro level model to macro level of national or regional level. The model could expand to serve different purpose of sustainability modeling assessment based on different new scenarios of government policy in the future.

References

[1] Presidential Decree No. 1/2006, *Instruksi Presiden No 1/2006. Penyediaan dan Pemanfaatan Bahan Bakar Nabati BBN sebagai Bahan Bakar Lain (Presidential Decree on Provision and Utilization of biofuel as Alternative Source of Fuel)*, Republik Indonesia, Editor. 2006.

[2] Biofuel National Team, *Blueprint 2006-2025: Pengembangan Bahan Bakar Nabati untuk Percepatan Pengurangan Kemiskinan dan Pengangguran (Biofuel Development for Acceleration of Poverty and Unemployement Reduction)*, Departemen Energi dan Sumber Daya Mineral (Ministry of Energy and Mineral Resources), Editor. 2006, Republik Indonesia (Government of Indonesia): Jakarta.

[3] IPOB, *Indonesian Palm Oil in Numbers*, ed. I.P.O. Board. 2007, Jakarta: Indonesian Palm Oil Board. 27.

[4] Savitry, A. *Palm Oil: Indonesia Takes Top Spot*. 2006 [cited 2010; Available from: http://www.asiafoodjournal.com/article-3792-palmoilindonesiatakestopspot-Asia.html.

[5] Pusat Data dan Informasi Departemen Pertanian, *Statistik Perkebunan Indonesia 2007-2009 (Indonesian Plantation Statistics 2007-2009)*, in *Statistik Perkebunan Indonesia*, Pusdatin Deptan, Editor. 2009, Ministry of Agriculture, Republic of Indonesia: Jakarta

[6] Basha, S.A., K.R. Gopal, and S. Jebaraj, *A review on biodiesel production, combustion, emissions and performance.* Renewable and Sustainable Energy Reviews, 2009: p. 7.

[7] Murugesan, A., C. Umarani, R. Subramanian, and N. Nedunchezhian, *Bio-diesel as an alternative fuel for diesel engines—A review.* Renewable and Sustainable Energy Reviews, 2009. **13**(3): p. 653-662.

[8] Dillon, H.S., T. Laan, and H.S. Dillon, *Biofuels at What Cost? Government support for Ethanol and Biodiesel in Indonesia*, in *One of a series of reports addressing subsidies for biofuels in developing countries*. December 2008, The Global Subsidies Initiative of the International Institute for Sustainable Development: Geneva, Switzerland.

[9] Bromokusumo, A.K., *Indonesia Biofuels Annual Report*, in *Global Agricultural Information Network (GAIN) Report*, D. Voboril, Editor. 2009, US Department of Agriculture Foreign Agriculture Services.

[10] Koh, L.P. and J. Ghazoul, *Biofuels, biodiversity, and people: Understanding the conflicts and finding opportunities.* Biological Conservation, 2008. **141**: p. 2450-2460.

[11] Siriwardhana, M., G.K.C.Opathella, and M.K.Jha, *Bio-diesel: Initiatives, potential and prospects in Thailand: A review.* Energy Policy, 2009. **37**: p. 554-559.

[12] A.Z. Abdullah, B.S., H.Moontabadi, S.Bhatia, *Current Status and Policies on Biodiesel Industry in Malaysia as The World's Leading Producer of Palm Oil.* Energy Policy, 2009. **37**.

[13] Lam, M.K., K.T. Tan, K.T. Lee, and A.R. Mohamed, *Malaysian palm oil: Surviving the food versus fuel dispute for a sustainable future.* Renewable and Sustainable Energy Reviews, 2008. **Articel in Press**: p. 9.

[14] Krismurtono, M. and B.P. Naiola, *The Challenges of Biofuel Implementation in Indonesia: Environmental Prospect.* International Journal of Basic and Applied Sciences, 2010. **10**(6).

[15] Sterman, J.D., *Business Dynamics: System Thinking and Modeling for A Complex World*. 2000, Boston: The McGraw Hill Companies, Inc.

[16] Pahan, I., *Panduan Lengkap Kelapa Sawit: Manajemen Agribisnis dari Hulu hingga ke Hilir (The Complete Manual of Palm Oil: Agribusiness Management from End to End)*. 2008, Jakarta: Penebar Swadaya.

[17] Indonesian Oil Palm Research Institute, *Teknologi Pengolahan Kelapa Sawit dan Produk Turunannya (Production Technology of Palm Oil and Palm Oil Based Products)*, ed. L. Buana, D. Siahaan, and S. Adiputra. 2003, Medan, Indonesia: Indonesian Oil Palm Research Institute.

[18] Syukur S. and AU. Lubis, *Perhitungan Bunga Untuk Peramalan Produksi Jangka Pendek pada Kelapa Sawit (Interest Calculation for Palm Plantation Short Term Production Forecast)*. 1989, Pematang Siantar, Indonesia: PPP Marihat.

[19] Sunarko, *Budi Daya dan Pengelolaan Kebun Kelapa Sawit dengan Sistem Kemitraan (Partnership System in Managing Palm Oil Plantation)*. 2009, Jakarta: PT AgroMedia Pustaka. 178.

[20] Barani, A.M., *Memaknai Sebuah Anugerah: Sumbangsih Kelapa Sawit Indonesia bagi Dunia (Understanding Our Blessing: Indonesia's Palm Oil Contributions to the World)*. 2009, Jakarta: Ideals Agro Abrar. 118.

[21] Pardamean, M., *Panduan Lengkap Pengelolaan Kebun dan Pabrik Kelapa Sawit (Complete Management Manual of Palm Oil Plantation and Factory)*. 2008, Jakarta: PT AgroMedia Pustaka. 226.

[22] ISO 14040:2006, *Life Cycle Assessment: Principles and Framework*, in *Environmental Management*. 2006, International Organization for Standard: Geneva Switzerland.

[23] Guinée, J.B., *Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards*. 2008: Springer.

[24] Pleanjai, S., S.H. Gheewala, and S. Garivait, *Environmental Evaluation of Biodiesel Production*

from Palm Oil in a Life Cycle Perspective, in *The Joint International Conference on "Sustainable Energy and Environment (SEE)"* 2004: Thailand

[25] Thamsiriroj, T. and J.D. Murphy, *Is it better to import palm oil from Thailand to produce biodiesel in Ireland than to produce biodiesel from indigenous Irish rape seed?* Applied Energy, 2009. **86**: p. 595–604.

[26] Reijnders, L. and M.A.J. Huijbregts, *Palm oil and the emission of carbon-based greenhouse gases.* Journal of Cleaner Production, 2008. **16**: p. 477-482.

[27] Chavalparit, O., *Clean Technology for the Crude Palm Oil Industry in Thailand*, in *Environmental Policy Group*. 2006, Wageningen University: Wageningen, Gelderland, The Netherlands. p. 229.

[28] Hitchcock, D. and M. Willard, *The Business Guide to Sustainability: Practical Strategies and Tools for Organizations*. 2006, London: Earthscan.

[29] Epstein, M.J., *Making Sustainability Work: Best Practices in Managing and Measuring Corporate Social, Environment and Economic Impacts*. 2008, Sheffield, UK: Greenleaf Publishing Limited.

[30] Blackburn, W.R., *The Sustainability Handbook: Complete Management Guide to Achieving Social, Economic and Environment Responsibility*. 2007, London, UK: EarthScan Ltd.

[31] Barlas, Y., *Formal Aspects of Model Validity of System Dynamics Type of Simulation Model.* European Journal of Operational Research, 1996. **42**: p. 59-87.

[32] Yulianto, A., *Minyak Bumi Pengaruhi Harga Minyak Nabati (Oil Price Affecting Biofuel Price)*, in *Info Sawit Magazine*. 2009, PT. Mitra Media Nusantara: Jakarta. p. 20 - 22.

[33] Amri, Q., *Klaster Industri Hilir Kelapa Sawit di Riau: Menunggu Legitimasi Pemerintah (Palm Industrial Clusters in Riau: Awaiting Government Approval)*, in *Info Sawit Magazine*. 2009, PT. Mitra Media Nusantara: Jakarta. p. 49.

[34] International Energy Agency (IEA), *World Energy Outlook 2010*. 2010, Paris Cedex: International Energy Agency Publishing.

[35] Hidayatno, A., Y.M. Zagloel, W.W. Purwanto, Carissa, and L. Anggraini, *Cradle to Gate Simple Life Cycle Assesment of Biodiesel Production in Indonesia* Makara Seri Teknologi - Universitas Indonesia, 2010. **Article In Press**.