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Doctoral Dissertation

Environmental Evaluation of Agro-Product Supply Chain: Indonesian Palm Oil and Japanese Green Tea Case Studies

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ABSTRACT

The growing global demand for agricultural product has driven the increasing production by exploring natural ecosystem and using agricultural chemicals. On the other hand, the demand itself creates economic opportunities. Therefore, the environmental evaluation of agricultural product by considering supply and demand is necessary. The general objective of this PhD thesis is to develop a dynamic supply-demand model to analyze potential environmental impacts resulting from the agriculture sector, using two case studies of the Indonesian palm oil (IPO) and the Japanese green tea (JGT). Palm oil is a representation of agricultural product that exploring natural ecosystem to meet the growing demand. While, Green tea is for using the pesticides to meet the growing demand. More specifically, the following descriptions are the stages of study to meet the general objective.

Chapter 2 analyzes the moratorium policy (MP) on new concessions for use of forest and peatland areas under reducing emissions from deforestation and forest degradation (REDD-plus) cooperation in Indonesia by focusing on one economic sector that relies on forest conversion and use for its business activities. The developed model is used to clarify the impact of MP on the environment and the economy of Indonesia using a case study of the palm oil industry sector. A scenario-based approach is conducted to extrapolate two basic scenarios of with and without the MP. Three scenarios describing the implications of the moratorium policy were examined in this study. The model has demonstrated that the MP helps to reduce CO_2 emissions from deforestation. However, the reduction is temporary or only to halt temporary environmental degradation. The

environmental degradation may arise again to the next period after the MP finished. On the other hand, the IPO industry will experience a breakdown effect in the palm oil production capacity. In addition, the breakdown effect last sufficiently long compared to the period of the MP, within a minimum of 10.5 years. This depicts the Indonesia should be prepared to weather the economic slowdown as the result of MP implementation since many economic sectors in Indonesia that rely on the forest.

Chapter 3 clarifies and estimates the historical environmental loads generated by each production supply chain of the IPO industry. In particular, significant focus is placed on Greenhouse Gas (GHG) emissions during the period 2004–2014. The model focused on estimated GHG emissions derived from land use changes and energy use based on fossil fuel and waste utilization. Based on the practical application of the model, the IPO industrial sector generated net GHG emissions of approximately 0.868 Tg CO_2eq per year during the period 2004–2014. The model demonstrated that plantation production chains also serve as an important source of carbon sequestration for the palm oil industry. Until 2014, carbon sequestration in the production chain contributed to reduce the Global warming potential (GWP) by nearly one-third based on total GHG emissions as a result of the IPO industry activities. Therefore, the GHG intensity of palm oil actually decreased over time. Furthermore, we found that the GHG emissions from fossil fuel-based energy are lower than the waste fuel-based energy within the production supply chain boundary. The cumulative difference was approximately 15×10^{-3} Tg CO_2eq for one decade.

Chapter 4 continues developing the model for assessing other agricultural products and environmental issues. The developed model is used to clarify and estimate the exposure pathways of pesticides on tea plantations using a case study of Shizuoka Prefecture, Japan, and an improvement to the Japanese good agricultural practice (GAP) is proposed. Although JGT is well known product but it cannot enter some countries due to the MRL values of some pesticides are still higher than the Codex Alimentarius Commission (CAC) or European Union (EU). Despite the studies to quantify and determine the pesticide residue and maximum residue limits (MRL) values for tea are generally performed through supervised field trial, this study use modeling for the estimation. Two pesticides, Azoxystrobin and Clothianidin, were analyzed using the model for a given set of circumstances. The results indicate that the implementation of a fixed preharvest interval (PHI) time, which is a crucial provision in the GAP, is not appropriate. The reason for this is that the dissipation rates of pesticides in tea leaves vary with the timing of the pesticide application and are influenced by factors specific to the plantation area. The dissipation rates are 1.5–3.9 days for Azoxystrobin and 3.8–9.5 days for Clothianidin. This study also clarifies that incorporating plantation-area-specific factors, such as temperature, in the GAP guidelines are essential to ensure that pesticide residues are lower than the desired level. Furthermore, to produce good-quality and safe green tea, the GAP should provide detailed and precise guidelines for the timing of pesticide application and formulation of the dosage treatment. These guidelines should be determined by considering specific provisions for the harvest times of fresh tea leaves.

Chapter 5 conducts a preliminary comparative study on the environmental load between IPO and JGT in order to investigate the key environmental issue in both agricultural products that probably have a significant impact on human health. Although IPO and JGT have different key environmental issues, both issues culminate on human health and eventually have fallen as global trade barriers. Land use change (LUC; i.e., forest conversion) associated with the GHG emissions has served as a key issue for the IPO. Total disability adjusted life year (DALY) resulted from the GHG emissions of LUC and energy use in whole production supply chain of palm oil industry in Indonesia is about 6418310 DALYs. Instead of LUC, the important issue in JGT is more to the pesticide residue in its final product that is measured by MRL value, which it is not a concern yet in the palm oil. Although MRL for pesticide residue are not measuring the level of toxicity, it is crucial to make sure that the pesticides are applied according to the GAP which ensures the food safety for consumer.

By the studies, Chapter 6 concludes that to minimize the environmental impact from agricultural product due to exploring of natural resources, the governance of LUC should be priority handled in order to reduce the environmental degradation. The MP is only an initial measure for the governance of LUC. The critical analysis for further policy and strategy which prepared during MP period is necessary. Furthermore, to minimize the environmental impact from agricultural product due to the use of pesticides or agricultural chemicals, GAP should provide detailed and precise guidelines on the timing of pesticide applications, formulation of dosage treatments considering specific provisions for the harvest times. Thus, incorporation of factors specific to individual plantations for the GAP guidelines and the PHI that is not implemented at fixed days, are essential to maintain pesticide residues under the desired levels. Moreover, developing the model which is able to directly compare the environmental impact of various agriculture products by using the same impact category, such expressed in DALY, are good for the future work.

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LIST OF ABREVIATIONS

BAU	Business As Usual
CAC	Codex Alimentarius Commission
CH_4	methane
CO_2	Carbon Dioxide
CO_2eq	CO_2 equivalent
CPKO	crude palm kernel oil
CPO	Crude Palm Oil
EU	European Union
FFB	Fresh Fruit Bunches
GAP	Good Agriculture Practice
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GPO	Global Palm Oil
GWP	Global Warming Potential
IPOPA	Indonesia Palm Oil Plantation Area
IPO	Indonesia Palm Oil
LUC	Land Use Change
MAORI	Ministry of Agriculture Republic Indonesia
MAPE	Mean Absolute Percent Error
MC	Mobile Combustion
MRLs	Maximum Residue Limits
MP	Moratorium Policy
MP-1	First Phase of Moratorium Policy
MP-1	Second phase of Moratorium Policy
N_2O	Nitrous Oxide
OER	Oil Extraction Ratio
PHI	Pre-Harvest Interval
POC	Palm Oil Consumption
POME	Palm Oil Mill Effluent
R^2	Coefficient of Determination
REDD	Reducing Emissions From Deforestation And Forest Degradation
SC	Stationary Combustion
SD	System Dynamics
TR	Tropical Rainforest

USDA-FAS	United States Department of Agriculture-Foreign Agricultural Service
USD	United States Dollar

CHAPTER 1

INTRODUCTION

1.1 Background

1.1.1 Agriculture, Economy and the Environment

The demand for agricultural products is growing in line with demographic and economic growth. According to Alexandratos and Bruinsma (2012), annual world agricultural production would need to increase 60 percent (%) by the year 2050 compared to 2005/2007. It consists of 77% increase in developing countries and 24% increase in developed countries.

Demand and supply has become an international process, no longer restricted to nations or regions (Vorst et al. 2007). Owing to the law of supply and demand that is naturally applied, the demand itself creates economic opportunities for many countries. It even plays a prominent role in the economic development of the countries, the palm oil is one such example. Indonesia became the largest producer of palm oil in the world which surpassed Malaysia in 2006 that contributed 44% of the global production (USDA-FAS 2007). Furthermore, data of USDA (2015) in 2014 reported that the Indonesian palm oil contributed up to 54% of the global production. It shows that the IPO market share has increased 10% within eight years. Therefore, it is not surprising if the palm oil industry is a vital agricultural industry for Indonesia. It contributes 6% to 7% of Indonesia's gross domestic product (GDP), and approximately 3.7 million people in Indonesia are involved in the industry (RSPO 2012). Moreover, this industry has always been the biggest and sole non-fossil fuel commodity (coal, oil, and gas) of Indonesia in terms of export contribution or the second largest after the dominance of coal exports (Alfian 2011) (Herlinda 2014).

In addition to bring economic benefits to the countries, the agricultural industries also burden it with related environmental impacts. Agriculture production has modified the natural landscape more than any other human activity (Clay 2004). Moreover, to increase the production, the agricultural chemicals are intensively used to reduce yield losses caused by pests and diseases. Although the agricultural chemicals are developed through very strict regulations, serious concerns about the use have been raised about health risks resulting from both occupational exposure and residues in food and drinking water (Damalas & Eleftherohorinos 2011).

As production increases to meet the growing demand, the environmental impacts from natural or anthropogenic resource use also increase. Environmental impacts resulting from the agricultural industries exist in each production supply chain. It has multiple potential environmental impacts on a local and global scale, as indicated by various documents. Thus, there is a trade-off between production in agriculture to meet the world's future needs and the environment. Accordingly, environmental problems related to agriculture will be more serious in the future.

1.1.2 Material Flow Analysis

In the environmental management, measuring the environmental impact to human or to the environment itself is a crucial thing. There are several tools that commonly used to assess the environmental impact, such as Life Cycle Assesment (LCA), Environmental Risk Assessment (ERA), Material Flow Analysis (MFA), Cost-benefit analysis (CBA), Input-Output Analysis (IOA), etc (Wrisberg et al. 2002) (Sonnemann et al. 2004) . MFA is a widely used in environmental. It is an excellent tool which can apply not only for materials, but also for specific substances. Thus, MFA covers the Substance Flow Analysis (SFA). Furthermore, MFA in the context of environmental management can be utilized for environmental policy analysis. MFA is defined as a systematic assessment of the flows and stocks of the materials within a system defined in space and time, and the results of MFA can be controlled by a simple material balance comparing all inputs, stocks, and outputs of a process (Brunner & Rechberger 2004).

Research using MFA is usually conducted to analyze the bulk material such as aluminum (Bertram et al. 2009), copper (Gloser et al. 2013), steel (Park et al. 2011). It is because MFA may help to identify and analyze the flows of material added to and removed from the system. Thus, MFA is appropriate tool to investigate the flows and stocks of any material-based system which can give insight into the behavior of system (Brunner & Rechberger 2004). In practice, MFA might be used either static or dynamic approach (Wrisberg et al. 2002) (National Research Council 2004).

1.1.3 Systems Modeling

The system is a set of interacting or interdependent components forming an integrated whole. System modeling is the use of model to conceptualize and construct the systems. It is mainly based on systems thinking -the ability to see the world as a complex system(Sterman 2000)-, to view systems in a holistic manner, by viewing and considering something as parts of an overall system, rather than separated parts.

A model is a substitute for some real equipment or system. Therefore, the nature of models is simplifications and approximations of the real system. However, models have a long history as tools for helping to explain scientific phenomena of the real system and predicting outcomes in settings where empirical observations are limited or not available (National Research Council 2007a). The model is often divided into two categories of static and dynamic (Ford 1999).

(a) Static model, it helps to learn about behavior of a system at rest. For instance, in the economic field, such models are to calculate the price of a product that will motivate producers to make exactly what the costumers wish to buy when the forces of supply and demand are in balance (market prices will be held constant over time). In the engineering field, it is used to calculate the forces needed to keep an object at rest.

(b) Dynamic model, it helps to think about how a system changes over time. For instance, a dynamic model may explain the economic forces needed to cause a nation's economy grow over time (economic field) or the physical forces needed to cause a rocket to accelerate (engineering field). Dynamic models also help to understand the behavior of systems overtime, for instance, an ecologist might use a dynamic model to explain if the oscillations in predator populations will remain stable over time.

The value of a model arises when it is able to improve our insight and understanding more effectively than could be done by observing the real system. It can be a basis for experimental investigations at lower cost and in less time than trying changes in the actual system (Forrester 1961). Furthermore, it is easier to work with a substitute rather than with the actual system (Ford 2010).

The use of model for experiment (by simulation) help us to learn something new about the systems they represent, with new insights and better understanding then will come better instincts for managing environmental systems (Ford, 2010). It is central to the regulatory decision-making process, to do prospective analyses of policies including for estimating the possible future effects on the environment, human health, and the economy (National Research Council 2007b).

1.2 Problem Statement

The demand for agricultural products is growing parallel with demographic and economic growth. On the other hand, the demand itself creates economic opportunities for many countries. Accordingly, agriculture sector has created a huge industry to meet the demand. As its consequence, exploring and converting natural resources and using the agricultural chemical are inevitable to increase production. Those conditions have triggered the environmental impact which can influence either the environment or human. Tilman et al. (2002) mentioned the environmental impact of agriculture come from the conversion of natural ecosystem, from agricultural nutrient's pollution in aquatic, and from pesticide.

FAOSTAT data (2015) indicated that about 38.5% of the world's land surface in 2011 is used for agricultural area. It is most likely derived by converting natural forests. Thus, the key issue regarding environmental impact resulting from agricultural product is mainly coming from the extensive land use required to establish the vast monoculture crop plantation areas to meet the demand.

The environmental impact of agricultural product also comes from the use of agricultural chemical, particularly pesticide. In agricultural production, pesticide use is so imperative. It is estimated that the pesticide use worldwide is about 2 million Mg per year (De et al. 2014). Although pesticide helps to reduce the crop loss, it has a serious impact as well to environment and human (Zhang et al. 2011). One of the critical issues is related to pesticide residue in agricultural product which indicated by the maximum residue limits (MRLs) value.

One of the highly demanded of agricultural products is palm oil. Palm oil is the largest agricultural commodities which has the great increasing of productivity globally during the four decades from 1960s to 2000s (Clay 2004). Recently, the demand of palm oil still remains high around the world and Indonesia dominates the world market share of palm oil by 54% (USDA-FAS 2015). It implies more concern on environmental issue as the side impact of palm oil production. Palm oil is one example of agricultural products that illustrates exploring and converting natural resources has been inevitable to meet the demand. The palm oil industry in Indonesia is chosen because their great contribution to economic growth (positive aspect) and environmental degradation (negative aspect).

Another agriculture product that needs attention is green tea. It is becoming a worldwide popular beverage and increasingly consumed among people. Because its popularity, Green tea export are expected to increase along with the production increases. Some countries, such as Japan, are likely to consume their domestic product (Clay 2004). One reason why people are more interested to consume green tea is because the marketing of health benefit of green tea. The demand of green tea has driven the extensive use of agricultural chemicals to increase the production. Thus, green tea is a representation of agricultural product that using the pesticides to increase production to meet the growing demand. However, its use remains an important problem (Gurusubramanian et al. 2008). It brings environmental impact, particularly to human health.

Accordingly, environmental problems related to agriculture will be more serious in the future in line with growing demand. These environmental problems on a local and global scale should be understood for future critical decisions.

The environmental impacts related to the growing demand for agricultural products can be clarified and estimated by using a modeling approach. The attempts to assess the environmental impacts, LCA, MFA, and system modeling are widely used. In the case of palm oil studies associated with the environmental impacts, LCA is a commonly used method (Yusoff & Hansen 2007) (Pleanjai et al. 2007) (Soraya et al. 2014) (Kittithammavong et al. 2014). But in the context of limited data available particularly in the developing countries, a dynamic MFA is an alternative method which is feasible to use. In case of green tea, the abundance of study about pesticide residue using field trial is existed but it is very limited when it comes to the modeling use. Since the field trial usually time and cost consuming, this present study try to estimate the good practice of pesticide use through system modeling that also using a dynamic MFA.

The extension use of existing standard MFA is being explored and encouraged extensively by scientists or economists (National Research Council 2004). It requires other tools and analytical approaches, such dynamic assessments (changes over time), multilevel assessments (e.g., how state-level MFA are related to national MFA), and culturally related assessments (e.g., how changes in population diversity will be reflected in materials use). In the context of environmental studies, dynamic approach assessment is appropriate to apply because it involves many factors which are in dynamic state. This approach is strongly related to the system thinking that that viewing and considering something as parts of an overall system rather than as separate parts (a system analysis in a holistic manner). Thus, the term of 'dynamic' in this study is referred to system dynamics (SD). SD has been acknowledged as an effective tool to depict complex and dynamic interactions among different systems and widely used for policy analysis and strategic planning in many fields.

1.3 Research Objective

The general objective of this study was to develop a dynamic supply-demand model for analyzing the potential environmental impacts resulting from the agriculture sector using two case studies of the Indonesian palm oil and the Japanese green tea.

By application of the model, this PhD thesis is aimed:

1. To analyze the future impact of moratorium policy (on new concessions for the conversion of forest and peatland) in Indonesia's economy and environment.
2. To clarify and estimate the historical environmental loads of Indonesian palm oil, particularly for GHG emissions derived from land use change and energy use.

3. To clarify and estimate the exposure pathways of pesticides on tea plantations using a case study of Shizuoka Prefecture, Japan, and an improvement to the Japanese good agricultural practice (GAP) is proposed.
4. To conduct a preliminary comparative study on the environmental load between Indonesian palm oil (IPO) and Japanese green tea (JGT).

1.4 Research Question

To meet the mentioned objectives previously, this study intends to answer the following questions:

1. What is the future impact of Moratorium Policy on the environment and economy of Indonesia in case of palm oil industry?
2. How is the past environmental loads generated by the production supply chains of palm oil industry in Indonesia?
3. How is the development and application of model for other agricultural products and environmental issues, green tea associated with the use of agricultural chemicals?
4. What is the critical environmental issue for the Indonesian palm oil and the Japanese green tea that probably have a significant impact on human health?

1.5 Scope

This research focuses on the development and the application of a dynamic MFA model related to the environmental impact of agricultural product by using two case studies, palm oil and green tea. This study is limited to assessing the environmental impact from converting natural resources and using the pesticide in agriculture product.

1.6 Framework

Figure 1-1 depicts the framework of this study. It depicts loop or iterative processes to develop the model of this study. The stages of model development divide into seven main stages as follows.

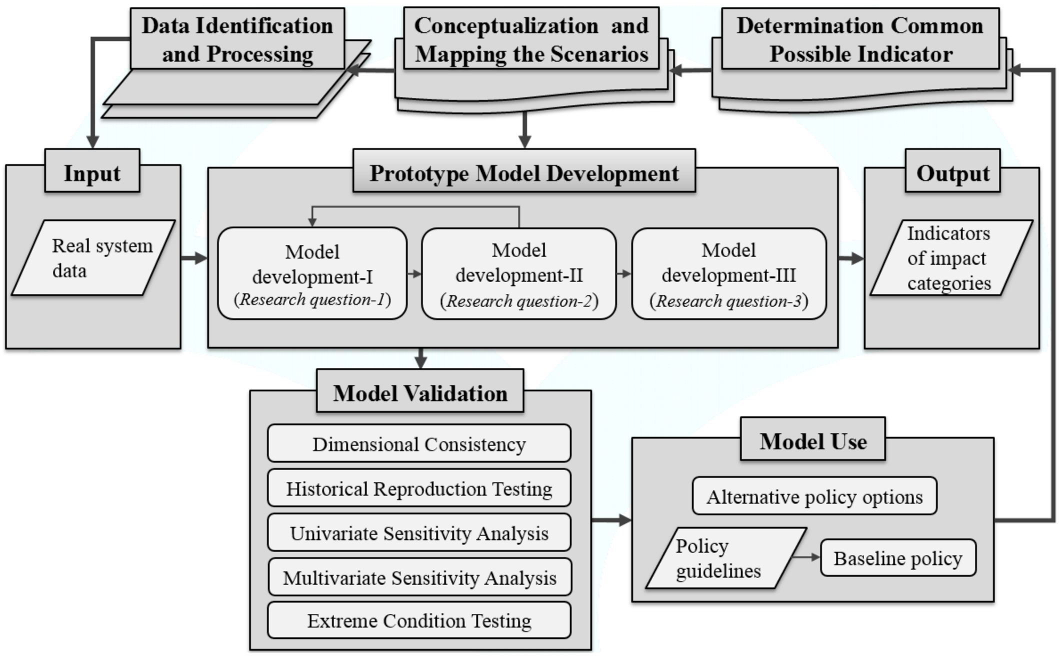

Figure 1-1. The thesis framework.

(a) Getting better acquainted with the problem, be specific with the key variables and its concepts that we must consider (problem identification).

(b) Making the scenario of theme being studied, based on a set of theories that explain it and descriptions/current situations of real system, including assumptions (model conceptualization).

(c) Converting the scenario into formal model, to construct the mathematical model of the variable relationships and transfer into computer simulation software (model formulation).

(d) Conducting the model experiments, to adjust the model by using the real system data until a target pattern, the desired system behavior is produced (model simulation).

(e) Testing the model, to reveal errors, flaws, limitations, shortcomings of the model and build confidence (model validation).

(f) After the base case has been obtained, assigning the model with variation of policy designs for improvement (Model development).

(g) Using the model to gain new insights into and understanding about the systems being studied and propose the most promising policy alternatives (model use).

However, the iterative processes of trial and error must be applied in each step of the modeling process above. It is not a linier sequence of steps, results of any step can yield insights that lead to revisions and redesigns in any earlier step (Sterman 2000)(Ford 2010).

Regarding the model validation, many modelers have long recognized and argued that validation models cannot establish the truth (Sterman 2000). Although the model was constructed using sophisticated software and a high-powered computer, the model is still a simplification of the real system (Ford 1999). The model validation procedures were designed to reveal errors, flaws, limitations, and shortcomings of the model, which could be fixed by revising the concepts and formulations of the model. Thus, the procedures are eventually intended to build confidence that the model is useful in order to enhance our insight and understanding relative to the themes being studied.

The fundamental model that are used in the dissertation is constructed and formulated by basic dynamic flow and stock equations which provide quantitative information over time about the mass that enter, stay, and leave throughout the system. The stock materials (m_{stock}) for any time (t) are calculated by the difference between input and output flows over time span (t_0 – t) (Brunner & Rechberger 2004).

$$m_{stock}(t) \quad = \quad \int_{t0}^{t} m_{input}(s)ds - \int_{t0}^{t} m_{output}(s)ds + m_{Stock}(t_0)$$

This study used a computer simulation modeling of system dynamics and analytica educational professional to implement the model of this study.

The data used in this study were from secondary data sources of online databases, textbooks, and scientific, including unpublished documents that we obtained from our plantation visit survey. For the statistical data mainly obtained from the World Bank, the United State Department of Agriculture (USDA), the Ministry of Agriculture Republic Indonesia (MAORI) and Badan Pusat Statistik Indonesia (BPS-Indonesia). We used historical data for each variable at least for 10 years. After statistically processed, the data were used as a base for simulating the model.

1.7 Outline of Thesis

This PhD thesis was organized as following. *Chapter 1* introduces the backgrounds of the research, the objective of the research intends to answer the question arises, the scope and definition of terms using in this research. *Chapter 2* provides analysis about the impact of MP on the environmental and economy of Indonesia in case of palm oil by developing a model using dynamic MFA concept. *Chapter 3* illustrates about the development and application of the model in chapter 2 to estimate input and output flows in each production supply chain of the palm oil industry in Indonesia. *Chapter 4* explains the development and application of the model to assess other environmental issues in other agricultural product, in this case is green tea associated with the use of pesticide. It is intended to clarify and estimate exposure pathways of pesticide on tea plantation in order to propose an improvement to Japanese GAP guidelines. *Chapter 5* describes a comparative study of IPO and JGT in the perspective of environmental loads associated with human health. The next chapter (*Chapter 6)* summarizes the contribution of this study as an effort to get insight and understanding to reduce the environmental impact resulted from the production of agriculture commodities.

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CHAPTER 2

SYSTEM DYNAMIC MODEL DEVELOPMENT FOR EVALUATION OF THE MORATORIUM POLICY ON NEW FOREST AND PEATLAND CONCESSION UNDER BIRATERAL COOPERATION IN INDONESIA: PALM OIL INDUSTRIAL SECTOR CASE STUDY

2.1 Introduction

The Kyoto protocol has brought a new policy direction for climate protection using three market-based mechanisms: emission trading, the clean development mechanism, and joint implementation (Hansjurgents 2005). Since then, "greenhouse gas (GHG) emissions -most prevalently carbon dioxide (CO_2)-became a new commodity." (UNFCCC 2013). Countries that bond with the target GHG emissions reductions in the Kyoto protocol can reach a portion of their targets using the three market-based mechanisms, that is, "it does not matter where the emissions are reduced, as long as the emissions are removed from the planet's atmosphere." For instance, they can develop green investments in developing countries to meet their reduction target. Regarding the international carbon market-based mechanisms for climate protection, reducing emissions from deforestation and forest degradation (REDD-plus) is one of the various negotiating tracks set to succeed the Kyoto Protocol. REDD-plus is a new framework which acknowledges the importance of forests in addressing climate change and emphasizes providing financial compensation to participating countries are willing and able to reduce emissions from deforestation (Parker et al. 2009)(Cifor 2009).

With regard to the GHG emissions, Indonesia is recognized as the third largest emitter in the world, of which roughly 85% comes from land use change and forestry, this is largely due to the release of CO_2 emissions from deforestation (Sari et al. 2007). However, the Indonesian government is committed to reducing 26% to 41% of GHG emissions relative to the business-as-usual (BAU) level by 2020 (Yudhoyono 2009). A reduction of 26% may be attained using Indonesia own domestic sources, whereas a reduction of 41% can be completed with support from international partners. In accordance with the commitment, in May 2010, Indonesia and Norway signed a letter of intent for REDD-plus cooperation (Solheim &

Natalegawa 2010). Norway intended to provide funds of up to USD $1 billion for forest conservation programs to help significantly reduce deforestation -caused GHG emissions in Indonesia. Under that agreement, Indonesia agreed to enact a 2-year suspension on all new concessions for the conversion of peatland and natural forest. The bilateral agreement finally came into force 1 year later, in May 2011, when the Indonesian president signed Presidential Instruction No.10/2011, which enacted the 2-year suspension (termed the “first phase of moratorium policy (MP-1)”) (Edwards et al. 2011)(Yudhoyono & Astuti 2011).

Before the implementation of the MP-I, strong opposition arose from the palm oil industry sector, which was incorporated into the Indonesia Palm Oil Producers Association (GAPKI). They argued that the MP would hamper the industry’s plan to double the amount of production by 2020 to meet the growing global demand of palm oil (The Jakarta Post 2010). They also suggested to the Indonesian government that as a developing country, Indonesia must prioritize economic development over the environment. Moreover, Latul and Chatterjee (Latul & Chatterjee 2010) reported concerns that the MP may stymie palm oil production, creating a perception of land scarcity in Indonesia and increasing land prices by 30%–50% over current levels.

Regarding Indonesian palm oil (IPO), the industry is a vital agricultural industry that plays a prominent role in the economic development of Indonesia. Since Indonesia became the largest producer of palm oil in the world, it contributes up to 44% of global palm oil production, a figure that is continually increasing (USDA-FAS 2007). This industry has always been the biggest and sole non-fossil fuel commodity (the commodities being coal, oil, and gas) of Indonesia in terms of export contribution (Alfian 2011). It contributes 6% to 7% of Indonesia’s gross domestic product (GDP), and approximately 3.7 million people in Indonesia are involved in the industry (RSPO 2012). However, in addition to the economic advantages, some key issues regarding environmental impacts resulting from the industry exist, specifically in the plantation phase. It relates to the extensive land required to establish the vast monoculture palm oil plantations, most of which are obtained by converting natural forest. As indicated by various documents, these issues include climate change (i.e., plummeting carbon stocks), loss of biodiversity, the extinction of endangered animals, soil erosion, and air, soil, and water pollution (Brown & Michael F. 2005)(Greenpeace 2007).

Before the MP-1 expires in May 2013, there is debate among stakeholders in Indonesia as a result of the announcement by Indonesia's forestry minister that he will provide a recommendation to the President that the MP-I should be extended (Pasandaran 2012). As a result, strong rejection has come not only from industry association that rely on forest conversion and utilization but also from Indonesian House representatives. However, Indonesia's President had decided to extend the MP-I for a further two years, that is until 2015 (termed the "second phase of moratorium policy (MP-2)") (Yudhoyono & Roesyidi 2013). The total time of 4-years is a long enough for suspension on all new concessions, thus, the impacts of this policy must be understood for future critical decisions. In addition, answering unresolved questions, such whether this policy is in line with the green economy concept of Indonesia, should be conducted in the context of development that is in favor of economic growth and the environment (Laksono 2011). Hence, it is necessary to conduct an analysis that clarifies the impact of the moratorium policy (termed the "MP ", covers MP-1 and MP-2) by focusing on one economic sector that relies on forest conversion and use for its business activities. The dynamic problems presented previously that cover environmental concerns and economic activities can be modeled using the system dynamics (SD) approach. This study was undertaken to develop a SD model that clarifies the impact of the MP on the environment and the economy of Indonesia using a case study of the palm oil industry sector.

2.2 Method and Modeling Process

The development of the model of this study follows the SD methodology, provided especially in Forrester (1961), Sterman (2000), and Ford (2010). Figure 2-1 depicts the framework of this study that consists of the input, process, output, and feedback diagrams of the modeling process, including the model structure. Owing to the bilateral agreement linking the GHG emissions reduction with financial incentives, we first determine the sustainability indicators from environmental and economic perspectives that are relevant to the theme of study. To evaluate the MP, CO_2 emissions was selected as an environmental indicator that measures the effectiveness of MP implementation, and the CPO yield that is produced by the IPO was selected as the economic indicator for obtaining an overview of the forest use for economic purposes. We then designed two basic scenarios, the BAU scenario and the MP scenario. The BAU scenario is our descriptive scenario in the absence of the MP, whereas the MP scenario is a descriptive scenario of the MP implementation. The scenarios were subsequently formalized into the SD model. We first built the BAU model, which is a formalization of the description of the interrelationships among major variables in real systems (Figure 2-2). The BAU model is divided into sub-models of palm oil demand, palm oil plantation, and impact. When the BAU model is imposed on by the MP sub-model, it becomes an MP model. Each sub-model has main outputs that connect the relationship between sub-models. After the model is developed and it has successfully passed the model validation procedures, the model was used for experimentation (i.e., through simulation).

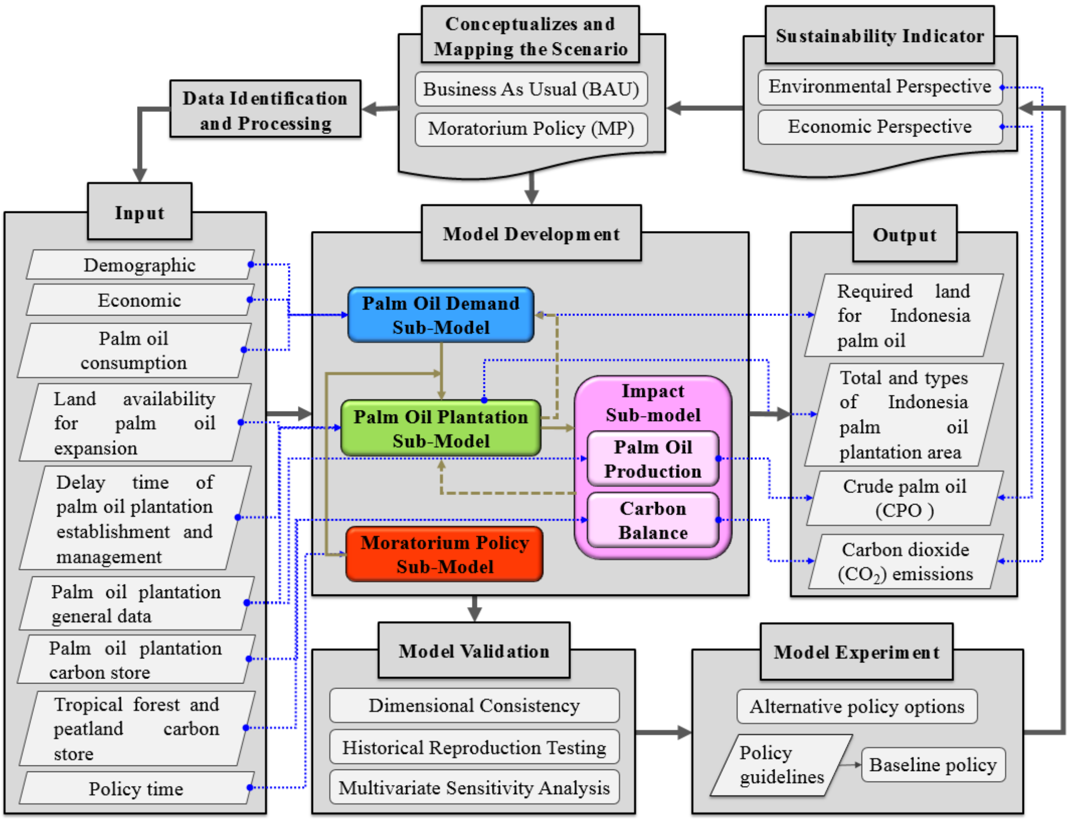


Figure 2-1. The study framework.

2.2.1 Model Conceptualization

2.2.1.1 Problem Definition

Because palm oil can be used as a versatile vegetable oil for a range of edible and non-edible products, including biofuel, it is the most highly demanded vegetable oil in the world. Thus, the expansion of palm oil plantations has been inevitable to meet the high demand of palm oil (Tan et al. 2009). Rising demand for palm oil triggers investment in the palm oil industry sector by establishing new palm oil plantations (i.e., expansion) to increase production to meet the demand. The demand of palm oil and land use change (LUC) is like two sides of the coin that cannot be separated. Hence, the key variables that we consider to be important variables that may depict the initial characterization of the problem are the global palm oil (GPO) demand and the Indonesia palm oil plantation area (IPOPA).

Figure 2-2 shows the historical data for the two key variables (USDA-FAS 2005, 2008, 2013a) (MOARI 2014), indicating that GPO demand in 2010 more than doubled compared to 2000, that is, from 28.1×10^6 Megagram (Mg) in 2001 to 52.1×10^6 Mg in 2010 for an average growth rate of 7.1% per year. Similarly, IPOPA increased from 4.7×10^6 hectare (ha) in 2001 to 8.4×10^6 ha in 2010 for an average growth rate of 6.8% per year. Thus, the data confirm that a relationship

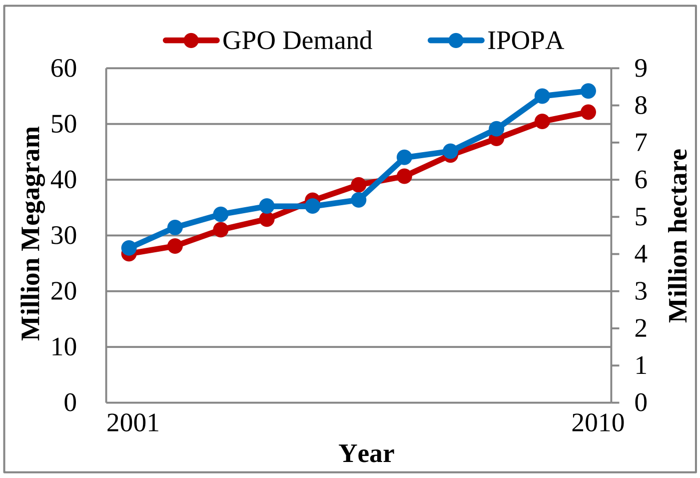


Figure 2-2. Historical global palm oil demand and Indonesia palm oil plantation area for 2001-2010.
The data confirm that a relationship exists between GPO demand and IPOPA, that is, the GPO demand is set to determine the LUC in Indonesia related to palm oil plantation expansion.

exists between GPO demand and IPOPA, that is, the GPO demand is set to determine the LUC in Indonesia related to palm oil plantation expansion. Furthermore, considering the analysis of the United States Department Agriculture (USDA), reliance on the Indonesian Palm Oil (IPO) production to meet future GPO demand cannot be avoided. Hence, both GPO demand and IPOPA trends are predicted to continue growing for the future (USDA-FAS 2010).

2.2.1.2 System Description

Understanding the impacts of the MP on the economy and environment of Indonesia lies in the relationship between the supply–demand system of palm oil. The demand side covers palm oil demand on the international level (GPO demand), national level (IPO demand), and the total land required for it. The supply side covers the fulfillment of required land for the IPO industry sector in order to meet the IPO demand.

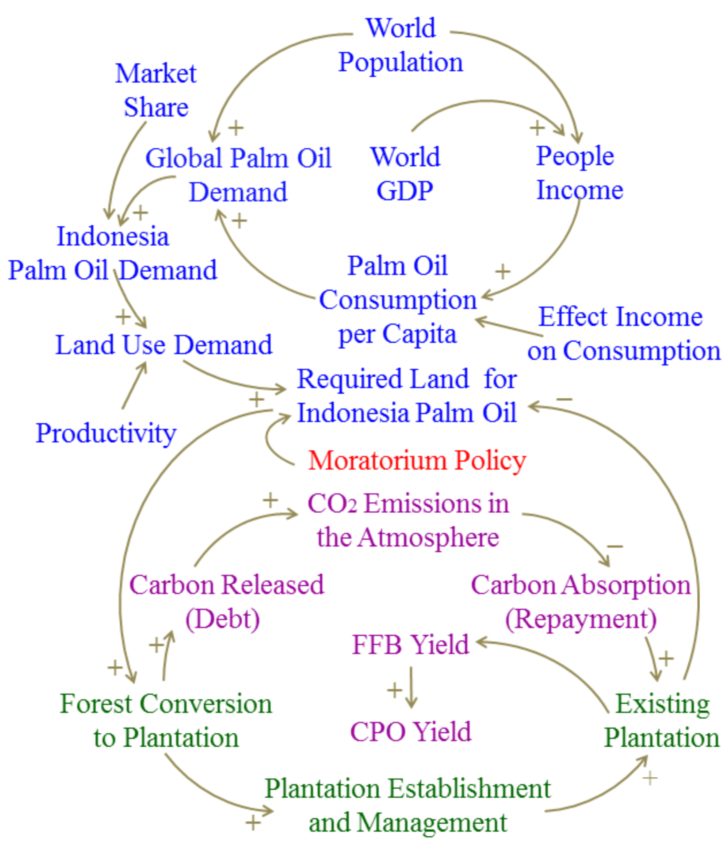


Figure 2-3. Structural relationships among system variables being studied.

Demographic change and economic growth are commonly used as the main factors affecting demand in all sectors. With regard to the GPO demand, Corley argued that future GPO demand will increase because of a growing world population and consumption per capita (Corley 2009). We adopted the Corley model, adding GDP growth and personal income as other variables that are assumed to determine palm oil consumption (POC) per capita.

The variables in the real system used to describe the system being studied can be identified and determined based on the key variables, current theories, and assumptions previously discussed. Figure 2-3 shows the interrelationships among selected variables of the real system that comprise the qualitative structure of the system being studied. The descriptions of the structural relationships are as follows.

a. The world demographic and economic situations, which are represented by growing population and GDP, respectively, create the GPO demand. The GPO demand is determined using global population and the POC per capita. The POC per capita is influenced by personal income, which is measured using GDP per capita. Personal income is assumed to affect or positively correlated with POC per capita.
b. The GPO demand automatically affects the IPO demand that is estimated using the IPO's market share in the GPO market. Owing to the law of supply and demand that is naturally applied in the business world, the IPO industry is assumed to always try to meet the IPO demand by expanding their plantation area to increase crude palm oil (CPO) production. The expansion of the plantation area is eventually added to the total IPOPA. Thus, total IPOPA is supply-side or is a variable that balances the land use demand.
c. Most palm oil plantations in Indonesia are located in former tropical forest, and the conversion of tropical forests to palm oil plantations continues to occur (Reijnders & Huijbregts 2008). Thus, the establishment of new plantation areas is assumed to be in tropical forests and peatland areas. The new plantation establishment releases carbon to the atmosphere (carbon debt). In contrast, the growth of palm oil crops in the plantation also absorbs carbon from the atmosphere (carbon repayment).

The SD model that is built in this study limits the production process of palm oil only in the plantation phase. Because the approach of the REDD-plus is to address the GHG emissions through forest conservation programs, limiting the production processes in the plantation phase is sufficient to gain insight and understanding about the policy intervention.

2.2.1.3 Moratorium Policy Scenario

The implications of the MP implementation were assumed ideally to be extreme circumstances (e.g., no palm oil plantation expansion occurs during the MP implementation) and based on actual situations that have occurred during the implementation of the MP-1. We used three scenarios for the MP implementation implications as follows.

1. The MP-1 suspends palm oil plantation expansion for 2 years from 2011, and the expansion continues after the MP expires in 2013 (ideal circumstance; MP-1 scenario).
2. The MP-2 suspends palm oil plantation expansion for 4 years from 2011, and the expansion continues after the MP expires in 2015 (ideal circumstance; MP-2 scenario).
3. The palm oil plantation expansion continues during the 4 year MP implementation, but at lower rates than those in the BAU scenario (actual situation; MP-3 scenario).

   The actual situation related to MP implementation (MP-3 scenario) refers to REDD-Monitor (Lang 2012), it has reported that the deforestation in Indonesia is continuing despite the implementation of the MP-I. It is mainly caused by forest concessions that were issued before the MP was signed. In addition, law enforcement is not effective. For instance, the Indonesian State Audit Board has revealed that one palm oil company conducted land clearing operations without a license from the Indonesian government.

2.2.2 Model Formulation

The SD stock variables in Figure 2-4 are shown as rectangular boxes that represent the accumulation of changes in the system due to connected flows. The flow variables that are shown like valves (double arrow and circle) represent the rate of change in the stock variables by adding or subtracting the values (i.e., inflows and outflows, respectively). The auxiliary variables (circle) contain calculations associated with other variables. Constant variables (diamond-shaped) contain constant/fixed values used for miscellaneous calculations on other variables. The information link variables or connectors (a single line) represent the relationship among variables within the system/model. Four subsystems corresponding to the model conceptualization and scenarios are built and discussed in the following sections.

2.2.2.1 Palm Oil Demand Sub-Model

The palm oil demand sub-model (Figure 2-4, blue color) primarily describes the extrapolation of future growth of GPO demand, including the required land for the demand, as described in Section 2.1.2, point A and B for the qualitative model. See Table 2-1: Items 1 to 11 for the quantitative model. World population growth and GDP are perceived as the main drivers increasing the demand of the GPO. The effect of personal income on POC per capita was estimated using regression analysis based on historical data from 2001 to 2010 (Table 2-1: Item 7). Whereas for the actual required land to meet the demand for the IPO is obtained by considering all existing palm oil plantations (Existing IPOPA) in Indonesia.

2.2.2.2 Palm Oil Plantation Sub-Model

The palm oil plantation sub-model (Figure 2-4, green color) depicts the establishment and management processes of the palm oil plantation, split into five stocks. One stock is used to record the land availability that specifically for palm oil expansion. The other four stocks (i.e., new, immature, mature, and unproductive IPOPAs) are used to track the plantation area types, describing the stock of the plantation and transitioning between stages based on their age. The management of a palm oil plantation is assumed to be a cyclical and repeating pattern: The palm oil crop is replanted when the crops in the mature plantations become unproductive, and they then repeat the stages of the plantation management process. All equations inside the plantation sub-model are listed in Table 2-1: Items 12 to 22.

2.2.2.3 Impact Sub-Model

There are two models inside the impact sub-model (Figure 2-4, maroon color), which are the carbon balance and palm oil production models. The amount of carbon emissions balanced between carbon debt and carbon repayment was assumed completely oxidized into CO_2 (i.e., multiplied by Molecular weight ratio of CO_2 to carbon). Carbon debt is carbon that is released to the atmosphere as a result of the IPOPA establishment, calculated using the stock of new IPOPA. Carbon repayment is carbon that is absorbed by the palm oil crops in the plantation, calculated using the stocks of immature and mature IPOPAs. The impact sub-model for CO_2 emissions of this study considers only the carbon balance as a result of the palm oil plantation expansion in and after 2010. Thus, immature and mature IPOPAs that absorb carbon are also from plantations established in and after 2010. The CPO yield was calculated based on the stock of mature IPOPA based on number of mature palm oil crops, number of fresh fruit bunches (FFBs) yield per palm crop, and number of FFBs required to produce one ton of CPO (i.e. the “oil extraction ratio (OER)”). The equations for the impact sub-models are listed in Table 2-1: Items 23 to 29 for ~~t~~he carbon balance and Items 30 to 32 for palm oil production.

2.2.2.4 Moratorium Policy Sub-Model

As previously described (Section 2.2.1.3), the MP is perceived as a variable that suspends or reduces forest conversion to palm oil plantations. The MP sub-model (Figure 2-4, rose color) is placed between the demand sub-model and the palm oil plantation sub-model, that is, between the variables of the total land use demand for IPO and the required land for IPO. For the MP-1 and MP-2 scenarios, the MP that is perceived as a variable that suspends the forest conversion can be explained as follows.

- If the land use demand for the IPO variable is perceived as mass flows through the MP variable, the MP variable can be seen as a process that captures and eliminates the mass flows for 2 years for the MP-1 (2011–2013) and for 4 years for the MP-2 (2011–2015), modeled using the STEP function (Table 2-1: Item 33).

- After the MP expires, it returns to the normal condition. That is, the MP variable transfers the mass flows into the required land for the IPO variable for the subsequent calculation. The formulation of the required land for the IPO variable for this scenario was modeled using the arithmetic IF function (Table 2-1: Item 34).

For the MP-3 scenario, the MP is perceived as a variable that reduces the forest conversion was modeled using the DelayMtr functions. Using this function, the MP-3 variable could be perceived as a process that captures the mass flows through a delay process. Thus, the material from the land use demand for the IPO variable undergoes a delay process inside the MP-3 variable, with an average delay time of 4 years (the validity period of the MP-I and MP-II). The distribution of the output value for the delay was assumed to be a first-order exponential material delay. After the MP expires, it returns to the normal condition; that is, the mass flows from the land use demand for the IPO flows directly into the required land for the IPO. The equations for the MP-3 scenario can be seen in Table 2-1: Items 35 and 36.

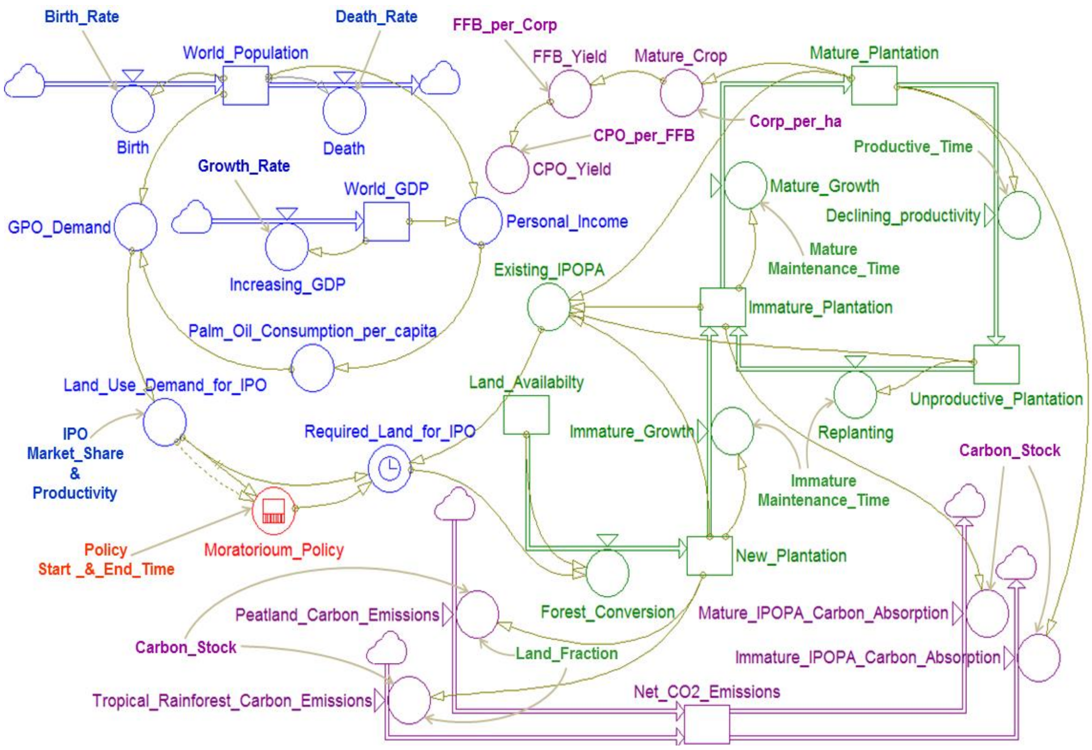


Figure 2-4. System dynamics model of this study.

Table 2-1. System dynamic formulas.

Item	Variable	Equation
1	World population (t)	= World population in 2010 + $\int_{2010}^{t}$ Births (s) ds $-$ $\int_{2010}^{t}$ Deaths (s) ds
2	Births (t)	= World population (t) × Crude birth rate
3	Deaths (t)	= World population (t) × Crude death rate
4	World GDP (t)	= GDP in 2010 + $\int_{2010}^{t}$ Increasing GDP (s) ds
5	Increasing GDP (t)	= World GDP (t) × GDP growth rate
6	Personal income (t)	= World GDP (t) / World population(t)
7	Effect of personal income (t) on POC per capita (t)	= 0.001 + [7.08×10^{-7} × Personal income(t)]
8	GPO demand (t)	= World population (t) × POC per capita(t)
9	IPO demand (t)	= GPO demand (t) × IPO market share
10	Land use demand for IPO (t)	= IPO demand (t) / IPO productivity
11	Required land for IPO (t)	= Land use demand for IPO (t) − Total IPOPA (t)
12	Land availability for IPOexpansion (t)	= Potential land in 2010 $-\int_{2010}^{t}$ Forest conversion to plantation (s) ds
13	Forest conversion to plantation (t)	= Required land for IPO(t) / Land preparation time
14	New IPOPA (t)	= New IPOPA in 2010 $+\int_{2010}^{t}$ Forest conversion to plantation (s) ds $-\int_{2010}^{t}$ New to immature growth (s) ds
15	New to immature growth (t)	= New IPOPA (t) / Immature maintenance time
16	Immature IPOPA (t)	= Immature IPOPA in 2010 $+\int_{2010}^{t}$ New to immature growth (s) ds $-\int_{2010}^{t}$ Immature to mature growth (s) ds $+\int_{2010}^{t}$ Replanting (s) ds
17	Immature to mature growth (t)	= Immature IPOPA (t) / Mature maintenance time
18	Mature IPOPA (t)	= Mature IPOPA in 2010 $+\int_{2010}^{t}$ Immature to mature growth (s)ds $-\int_{2010}^{t}$ Declining productivity (s)ds
19	Declining productivity (t)	= Mature IPOPA (t) / Productive time
20	Unproductive IPOPA (t)	= Unproductive IPOPA in 2010 $+\int_{2010}^{t}$ Declining productivity (s) ds $-\int_{2010}^{t}$ Replanting (s) ds
21	Replanting (t)	= Unproductive IPOPA (t) / Mature maintenance time
22	Existing IPOPA (t)	= $\sum$ IPOPA Type = New IPOPA (t) + Immature IPOPA(t) + Mature IPOPA (t) + Unproductive IPOPA(t)
23	Carbon balance (t)	= Carbon emission in 2010 $+\int_{2010}^{t}$ Peatland carbon emissions (s) ds $+\int_{2010}^{t}$ Tropical rainforest carbon emissions (s) ds $-\int_{2010}^{t}$ Mature IPOPA carbon absorption(s) ds $+\int_{2010}^{t}$ Immature IPOPA carbon absorption (s)ds
24	Net CO_2 emissions (t)	= Carbon balance (t) · Molecular weight ratio of CO_2 to carbon

Table 2-1. System dynamic formulas (continued).

Item	Variable	Equation
25	Peatland carbon emission (t)	= New IPOPA (t) × Land fraction for IPOPA · Peatland carbon stocks
26	Tropical rainforest (TR) carbon emission (t)	= New IPOPA (t) × (1 − Land fraction for IPOPA) × (TR above-ground biomass + TR below-ground biomass) × TR carbon fraction
27	TR below-ground biomass	= TR above-ground biomass × TR ratio below to above grounds biomass
28	Mature IPOPA carbon absorption (t)	= IF(Mature IPOPA (t) > Mature area 2010, [Mature IPOPA (t) − Mature area 2010] × IPOPA carbon stock accumulation in biomass, 0)
29	Immature IPOPA carbon absorption (t)	= IF(Mature IPOPA (t) > Immature area 2010, [Immature IPOPA (t) − Immature area 2010] · IPOPA carbon stock in biomass after 1 year growth, 0)
30	CPO yield (t)	= FFB yield (t) × OER
31	FFB yield (t)	= Mature crop (t) × FFB per palm oil crop
32	Mature crop (t)	= Mature IPOPA (t) × Palm oil crop number
33	Moratorium policy for MP-1 or MP-2 scenarios(t)	= STEP (Land use demand for IPO(t), Policy end time)
34	Required land for IPO (t) for MP-1 or MP-2 scenarios	= IF(TIME < Policy start time, Land use demand for IPO(t) − Total IPOPA (t), IF(Moratorium policy (t) > Total IPOPA (t), Moratorium policy (t) − Total IPOPA(t), 0))
35	Moratorium policy for MP-3 scenarios (t)	= DELAYMTR(Land use demand for IPO 1, Policy end time − Policy start time,1)
36	Required land for IPO (t) for MP-3 scenarios	= IF(TIME<Policy start time, Land use demand for IPO(t) − Total IPOPA(t), IF(TIME<Policy end time, Moratorioum policy (t) − Total IPOPA (t), Land use demand for IPO (t) − Total IPOPA (t))

2.2.2.5 Data and Simulation

We collected the required data/information from several online databases, textbooks, and papers in scientific journals or proceedings. For the statistical data mainly obtained from the World Bank, the USDA, and the Ministry of Agriculture Republic Indonesia (MAORI) databases, we used historical data for each variable over the 10 years from 2001 to 2010. All input data were used as a base for simulating the model listed in Table 2-2. We used several input data for our assumptions. For the initial conditions of the system (in 2010), the new IPOPA, unproductive IPOPA, and net CO_2 emissions were set to 0. This is mainly because there is no available data and setup for modeling purposes. After the data were determined and inputted, the simulation was conducted.

Table 2-2. Input data for model simulation.

No.	Variable	Value	Data Source
1	World population 2010	6,894,377,794 people	(World Bank 2013)
2	Crude birth rate	20 per 1,000 people	
3	Crude death rate	8 per 1,000 people	
4	World GDP 2010	63,135,994,837,272.7USD	
5	GDP growth rate	7.1%	
6	IPO market share	53%	(USDA-FAS 2013b)
7	IPO productivity	3.1 Mg ha^{-1}	(MOARI 2014)
8	Land preparation time	1 year	(Corley & Tinker 2003)
9	Immature maintenance time	1 year	
10	Mature maintenance time	1.75 years	
11	Productive time	22 years	(Ling 2012)
12	Potential land 2010	45,846,329 ha	(Drajat 2007)
13	Immature IPOPA 2010	1,799,663ha	(MOARI 2014)(USDA-FAS 2010)
14	Mature IPOPA 2010	6,024,960 ha	
15	Land fraction for IPOPA	14% (on peatland area)	(Hooijer et al. 2006)
16	Peatland carbon stocks	1450 Mg per ha	(Charman et al. 2008)
17	Molecular weight ratio of CO_2 to carbon	44/12	(IPCC 2006b)
18	TR above-ground biomass	350 Mg dry matter ha^{-1}	
19	TR ratio below to above grounds biomass	0.73 Mg root d.m. (Mg shoot d.m.)$^{-1}$	
20	Carbon fraction of above-ground biomass	0.74 Mg C (Mg d.m.)$^{-1}$	
21	IPOPA carbon stock in bio-mass after 1 year growth	5 Mg ha^{-1}	
22	IPOPA carbon stock accumulation in biomass	5 Mg ha^{-1} $year^{-1}$	(Dewi et al. 2009)
23	Palm oil crop number	130 crops ha^{-1}	(Corley & Tinker 2003)
24	FFB per palm oil crop	0.140 Mg $year^{-1}$	(Yusoff & Hansen 2007)
25	OER	0.218 Mg CPO (Mg FFB.)$^{-1}$	(Hayashi 2007)
26	Policy start time for the MP-1, MP-2 and MP-3 scenarios	2011	(Yudhoyono & Astuti 2011)
27	Policy end time for the MP-1 scenario	2013	
28	Policy end time for the MP-2 and MP-3 scenarios	2015	(Yudhoyono & Roesyidi 2013)

The simulation was run for a 10-year span from 2010 to 2020. This time horizon was deemed sufficient to depict the problem and to see the impacts. At first, the model simulated the BAU scenario to identify the extrapolation future situation without the implementation of the MP. The BAU scenario then was imposed by the MP (by adding the MP sub-model) to become the MP scenarios.

2.3 Model Validation

The model validation procedures are eventually intended to build confidence that the model is useful in order to enhance our insight and understanding relative to the themes being studied. To do so, historical reproduction and sensitivity analysis testing were conducted.

2.3.1 Historical Reproduction Testing.

For this test, we focused on the key variables (GPO demand and total IPOPA). The historical data series of both variables from 2001 to 2010 (Figure 2-2) was used to verify the model in extrapolating the trend. For this testing, the initial condition of the model was set at 2001 because the simulation started in 2001 and ended in 2010. The other parameters were set as fixed for the base run. The mean absolute percent error (MAPE) was used for assessing the behavior reproduction of the model.

Figure 2-5 shows a comparison of the data between the model output and the actual GPO demand data (Figure 2-5.a) and total IPOPA (Figure 2-5.b) in a scatter chart. The MAPE of GPO demand and total IPOPA are 4.6% and 4%, respectively. These numbers are under 10%, indicating that the agreement between the historical data and the simulation results was reasonable, because the model was able to reproduce the real system.

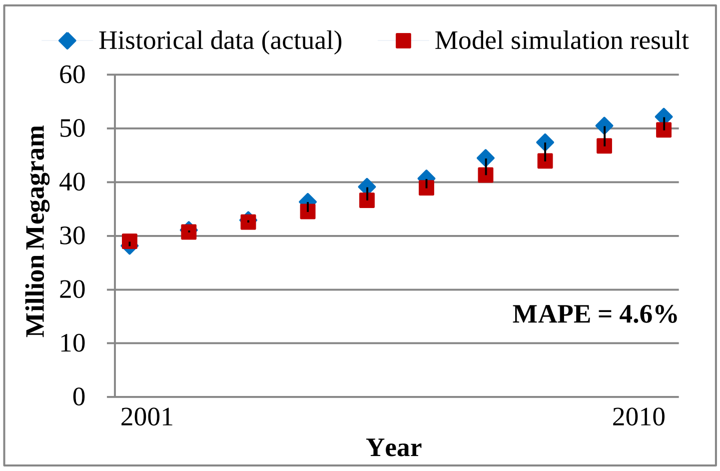
2.3.2 Multivariate Sensitivity Testing

Because a comprehensive sensitivity analysis that requires all combinations of assumption testing is not possible, selecting only a few scenarios of special interest for examination is sufficient (Morgan and Henrion, 1990). This sensitivity analysis was conducted using parameter combination testing (multivariate) packaged as the best-case, BAU-case (base run), and worst-case scenarios.

The worst-case scenario assumes that personal incomes may not be high in the future, that is, population growth increases rapidly and GDP increases at a slower rate. In addition, under this scenario, the IPO market share is small in the GPO market, and additional time is required to establish a mature plantation area. The best-case scenario is the opposite of the worst-case one. In total, this testing demonstrated sensitivity analysis using a combination of eight parameters that are likely to have high levels of uncertainty in the real system.

The simulation result showed that the behavior pattern of the three scenarios for GPO demand (Figure 2-6.a) and CPO yield (Figure 2-6.b) were identical, although they have different implications for each variable. The sensitivity analysis showed that the model was able to produce the same pattern of behavior imposed by a variety of assumptions that were still in the plausible range of uncertainty. This means that the uncertainty in many parameter inputs do not change our conclusion. Thus, the model is robust and sensitive to the changes.

a. Global palm oil demand.



b. Indonesian palm oil plantation area.

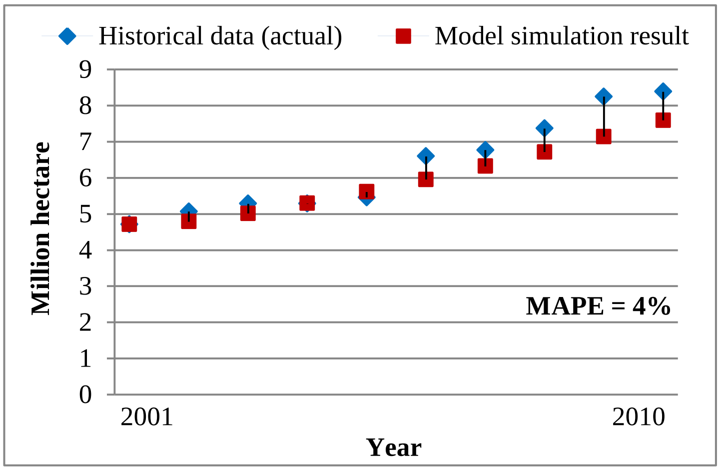
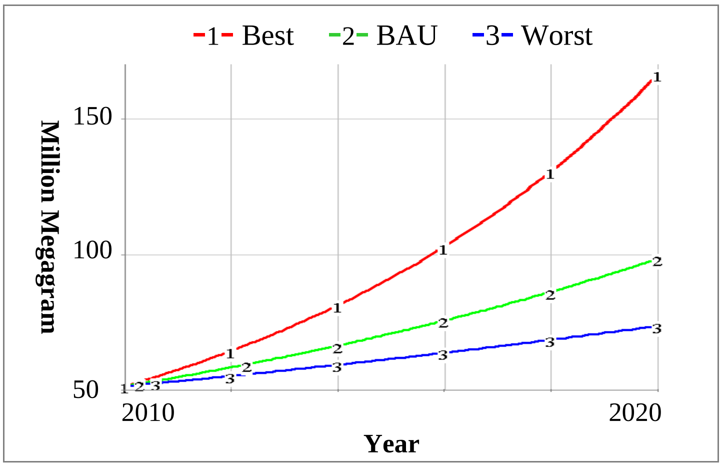


Figure 2-5. Model validation for historical reproduction testing

a. Global palm oil demand.



b. Crude palm oil yield.

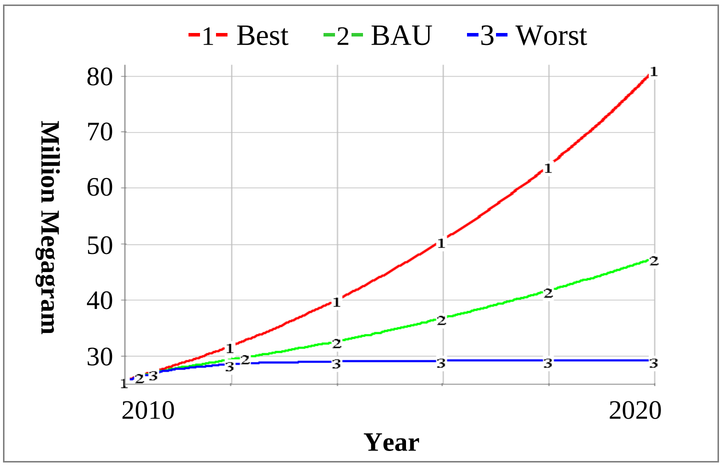


Figure 2-6. Model validation for multivariate sensitivity testing.
Worst-case scenario: The world population CBR and CDR are 21 per 1000 people (i.e., the highest rate measured in the historical data) and 8 per 1000 people (average rate from the historical data), respectively. The nominal GDP growth rate is 3.9% (the growth rate in 2002). The IPO global market share is 29.85% (the lowest value recorded from the historical data). The required times for the establishment and management of apalm oil plantation are 1.5, 1, 1.75, and 20 years for land preparation time, immature maintenance time, mature maintenance time, and productive time, respectively.
Best-case Scenario: The world population CBR and CDR are 14 and 8 per 1000 people, respectively. The nominal GDP growth rate is 12.75% (the highest rate measured in the historical data). The IPO global market share is 60%. The required times for the establishment and management of a palm oil plantation are 0.66, 1,1.75, and 30 years for land preparation time, immature maintenance time, mature maintenance time, and productive time, respectively.

2.4 Evaluation of Policy Option

2.4.1 Forest conversion to palm oil plantation

The model extrapolates that the total GPO demand in 2020 is projected to reach 98. 1×10^{6} Mg, whereas the total IPO demand is estimated to be approximately 52×10^6 Mg in 2020. According to such a level of demand, the total plantation area that ideally should be owned by the IPO industry by 2020 to meet the demand is approximately 15.7×10^6 ha. Thus, the total required land for the IPO to meet the demand is predicted to reach 8.2×10^6 ha during 2010–2020. Under the BAU scenario, the conversion of forest to plantations gradually increases in line with the demand at a rate of 0.74×10^6 ha annually. Under the MP scenarios, the forest conversion to plantation grows exponentially at first, and is then interrupted by the MP implementation. Thereafter, the forest conversion to plantations will shoot up after the MP period expired, followed by an exponential decline until reaching the BAU level. A peak of forest conversion followed by its exponential decline might be understood as follows: After the MP expires, the IPO industry tries to repay their lag in meeting the demand. They then increase their production capacity by boosting the expansion to try to meet the demand. Hence, the annual rate of forest conversion under MP scenarios will be higher than the BAU scenario, it reaches 0.79×10^6, 0.85×10^6, and 0.8×10^6 ha for MP-1, MP-2, and MP-3 scenarios, respectively. After a disturbance of the MP implementation, the rate of forest conversion to palm oil plantations under all MP scenarios returns to an equilibrium condition (i.e., balance between supply and demand); in this case, this is the BAU scenario.

2.4.2 CO_2 Emissions

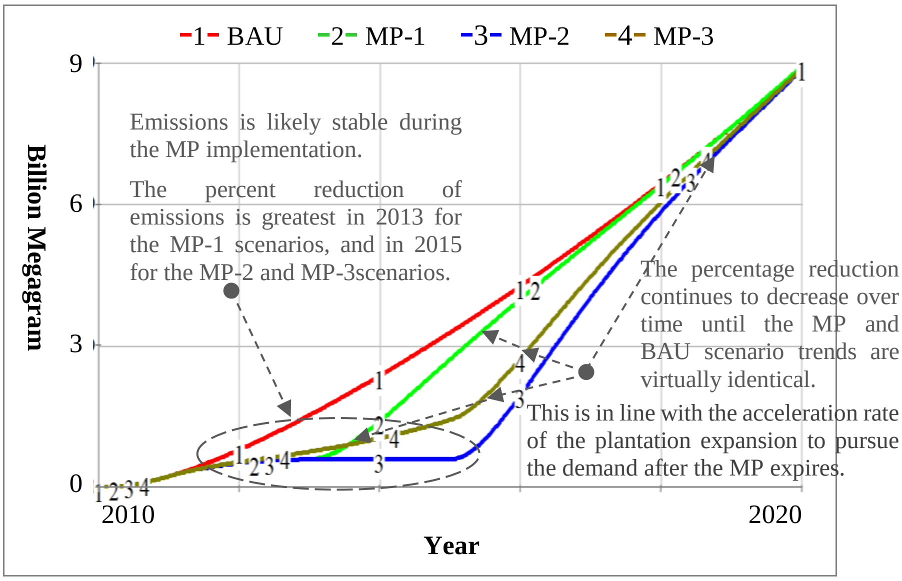
Because of IPO industry expansion, there is a substantial increase in CO_2 emissions for all scenarios (Figure 2-7.a). Under the BAU scenario, the model predicted a carbon debt as a result of the forest conversion to palm oil plantations during 2010-2020 is approximately 2.5×10^9 Mg, whereas the carbon repayment as a result of the growth of palm oil crops in the plantation is approximately 1.2×10^8 Mg. Thus, the total net CO_2 emission that cumulatively balances between carbon debt and carbon repayment multiplied by molecular weight ratio of CO_2 to carbon (44/12; table 2-2 no.17) during 2010–2020 reaches nearly 8.8×10^9 Mg. In contrast, Fig. 6.a shows that the MP implementation positively impacts CO_2 emissions reduction. CO_2 emissions are likely stable during the MP implementation; however, in the end, the trends are virtually identical. The impact of the MP on the reduction of CO_2 emissions by the year 2020 is projected to reach 2.9×10^9, 9.7×10^9, and 7×10^9 Mg for MP-1, MP-2, and MP-3 scenarios, respectively. The percent reduction of CO_2 emissions is greatest in 2013 for the MP-1, and in 2015 for the MP-2 and MP-3 scenarios; these are approximately 60%, 81%, and 58% for MP-1, MP-2, and MP-3 scenarios, respectively, compared with the BAU scenario. However, the percentage reduction then continues to decrease over time until the emission level under the MP scenarios return to the level of the BAU scenario. This is in line with the acceleration rate of the plantation expansion to try to meet palm oil demand after the MP expires. Thus, the MP on new forest concessions, which is only temporary (i.e., 2 years for MP-1 and 4 years for MP-2), is able to reduce CO_2 emissions, which are temporary as well.

Focusing only on the MP may not seem to have a significant impact on environmental amelioration for the long term. The model has demonstrated that the emission trend under the MP scenarios eventually returns to the BAU level. Hence, further strategy and policy instruments that are as a continuation of the MP are absolutely necessary. However, the MP can be an initial measure or a springboard for mitigating GHG emissions from deforestation and forest degradation. The time interval during the MP implementation can be used for the preparation of further policy formulations, including the facilities that are required. For instance, if an effective degraded land database is created, future palm oil plantation expansions will be placed on the correct land. By placing the new concessions of palm oil plantations on the degraded land, Indonesia receives both economic and environmental (i.e., reforestation) benefits.

2.4.3 Crude Palm Oil Yield

Assuming the required land to meet the demand is actually executed over time by the IPO industry sector, the IPO industry is projected to have a mature plantation area of 11.9×10^6 ha by 2020, and will be able to produce 47×10^6 Mg CPO. Figure 2-7.b shows the comparison between the CPO yield for the BAU and MP scenarios. The MP has a negative impact on the IPO industry sector, because it hampers the increase of the IPO industry's production capacity in line with the increasing demand. However, the IPO industry will eventually be able to smoothly

a. CO_2 emissions.



b. Crude palm oil yield.

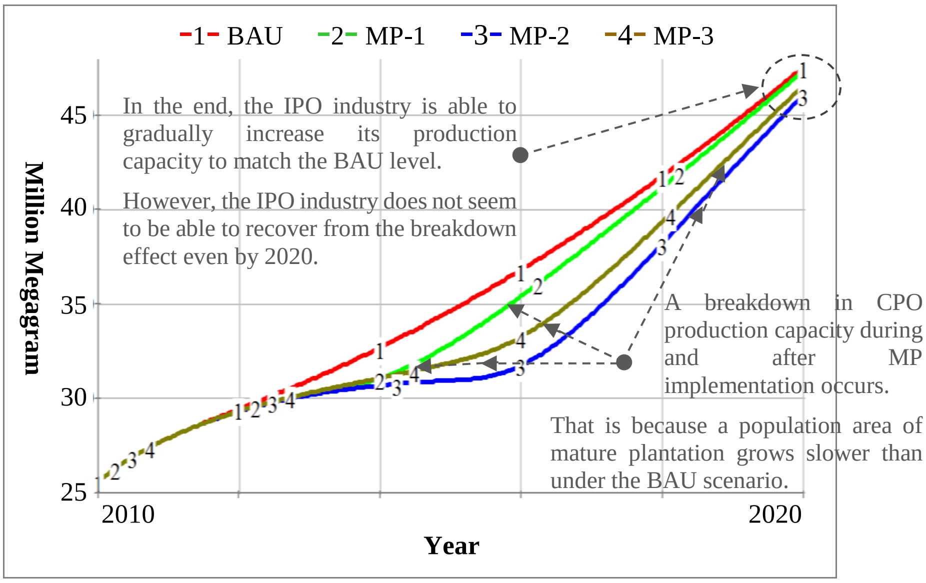


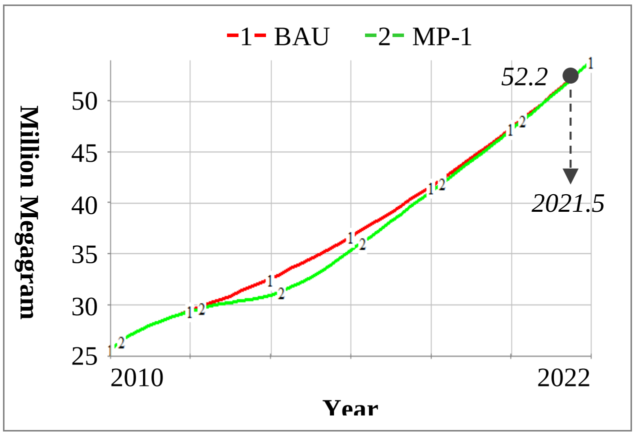
Figure 2-7. The simulation result of CO_2 emissions and crude palm oil yield over time from 2010 to 2020 under the BAU and MP scenarios.

increase their production capacity to match the BAU level. The IPO industry does not seem to be able to pay for the breakdown in the CPO production capacity as a result of the MP implementation even by 2020. The annual average CPO yield until 2020 is projected to decline by 1.9% (around 6.7×10^5 Mg), 6% (2.1×10^6 Mg), and 4.3% (1.5×10^6 Mg) for the MP-1, MP-2, and MP-3 scenarios, respectively. This declining yield occurs because the MP causes a temporary suspension of the palm oil plantation expansions, which automatically make the mature plantation population area grow slower than under the BAU scenario. Consequently, the production capacity of IPO industry is determined, and, thus, the MP hampers the IPO industry in meeting the market demand. The model also demonstrates that the IPO industry will experience a breakdown effect within a minimum of 10.5, 14 and 12,5 years for the MP-1, MP-2, and MP-3 scenarios, respectively (based on the simulation if the time horizon of the model is extended, see figure 2-8).

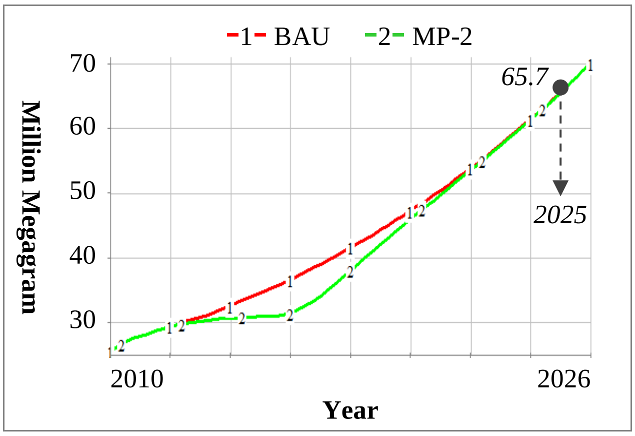
The declining CPO yield as a result of the MP implementation is perceived as a potential economic loss because of the failure to capture the economic opportunities (i.e., to fulfill the palm oil market demand). Thus, it is necessary to overview the potential economic loss. For the overview, we conducted a rough calculation of the cumulative value of the palm oil yield that is potentially lost during 2010 to 2020 by multiplying the declining CPO yield by the palm oil price. The total potential economic loss in the IPO industry sector during 2010–2020 is approximately 5.6, 17.1, and 12.5 billion USD for the MP-1, MP-2, and MP-3 scenarios, respectively. This value was obtained using a random simulation with various palm oil prices during July to December 2013, that is in the range of $723 to $810 USD per Mg (Index Mundi 2013). The total potential economic loss is actually higher than that value considering the other processes/aspects related to forest conversion to plantation area, such as the forest concession fee, the timber value from forest clearing, and job creation. From this illustration (rough calculation), in terms of finances, we can say that the potential economic loss cannot be offset by a financial from the bilateral agreement on REDD-plus cooperation. Moreover, the financial compensation payment depends on the achievement of Indonesia in reducing GHG emissions.

However, the MP could push the IPO industry sector to shift their method in increasing the production capacity. That is, to lead into activities that can improve the productivity of existing plantations rather than increase forest conversion. Thus, the deforestation rate and its environmental impacts can be avoided. The model experiment has demonstrated that if the IPO industry is able to improve their productivity (i.e., to gradually improve from an average of 3.1 Mg per ha in 2010 to

a. BAU versus MP-1 scenarios.



b. BAU versus MP-2 scenarios.



c. BAU versus MP-3 scenarios.

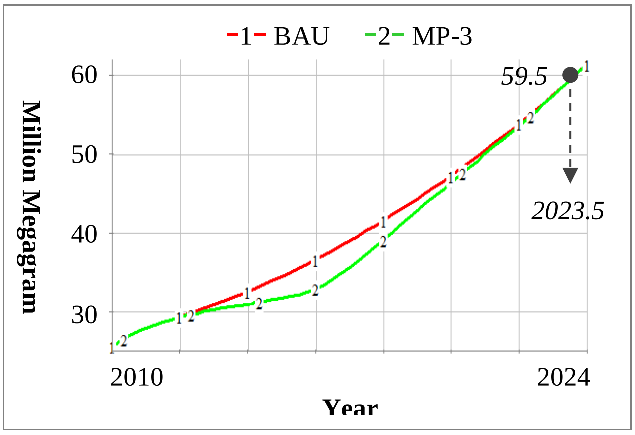


Figure 2-8. Breakdown in CPO production capacity as a result of the MP implementation (if the time horizon of the model is extended).

Since the MP implementation (in 2011), it takes 10.5 years (in 2021.5), 14 years (in 2025), and 12,5 years (in 2023.5) for the MP-1, MP-2, and MP-3 scenarios, respectively, to increase production capacity matches the BAU level.

4 Mg per ha in 2020), required land for IPO could be reduced by approximately 41% compared with the BAU scenario. For the existing IPO plantations, we found that to increase a planting density per ha is an option for improving productivity. The IPO planting density is around 130 palm crops per ha (Corley 2009), whereas in Malaysia reaches to 140-148 palm crops per ha (Yusoff & Hansen 2007)(Yusoff 2006). Increasing the density from 130 to 148 palm crops per ha will increase the productivity of 14% or to increase from 3.1 to 3.5 Mg of oil per ha. Another option is to use a good quality seed when replanting, it is essential not only for growing a strong and healthy crop but also for improving the yield. According to Basiron (2007), by intensive breeding and research cycles that have been conducted over the last 50 years, the yields of good quality seeds can reach more than 10 Mg/ha/year. In addition, It is believed that yield improvement of 18.5 Mg of oil/ha/year can be realised in the future if the breeding research continues. However, to implement properly best practices in plantation management is also an important factor to improve productivity.

2.5 Conclusion

This study presents an SD application to assist with policy analysis of a trade-off between GHG emissions reduction and economic growth with regard to the implementation of the MP under REDD-plus cooperation in Indonesia. The primary goal of developing this model is to enhance the understanding of the impacts of the MP implementation associated with the supply–demand mass flows of one economic sector of Indonesia that rely on the forest. Thus, we address that the model is not meant to predict the future or to produce a quantitative projection, which may not match the actual situation in the future.

The model has demonstrated that the MP noticeably reduces GHG emissions from deforestation. However, (i) the trend of GHG reduction is only temporary; that is, using only the MP seems to halt temporary environmental degradation or to shift the environmental degradation to the next period. (ii) Indonesia may face an economic slowdown as a result of the MP implementation. Furthermore, the slowdown effect will last sufficiently long compared to the period of the MP, mainly because of the declining productivity of Indonesia economic sectors that rely on the forest conversion and use, such as mining, timber/logging, palm oil, and numerous agricultural industries.

Referring to the results, the bilateral agreement on REDD-plus cooperation seems to not be in accordance with the green economy concept of Indonesia that provides equal attention to economic growth and the environment. Because the bilateral agreement is not economically viable for Indonesia, a payment for environmental services under the bilateral agreement is uncompetitive with the palm oil industry sector, which is only one of many economic sectors in Indonesia that rely on the forest. However, the MP can be an initial measure for mitigating GHG emissions from deforestation and forest degradation. Thus, whether the MP has long-term positive impacts on both economy and environment of Indonesia depends on further strategy and policy instruments, which as a continuation of the MP are absolutely necessary and should be prepared before the policy expires.

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CHAPTER 3

A MODELING APPROACH TO INVESTIGATE GREENHOUSE GAS EMISSIONS IN THE INDONESIAN PALM OIL INDUSTRIAL SECTOR

3.1 Introduction

Palm oil is an agricultural commodity in high demand and the 2014 global palm oil (GPO) demand was nearly double that for 2004, resulting in an average growth rate of 6.7% per year. Indonesia is the largest producer of palm oil and in 2014 the county contributed 54% of the global production (USDA-FAS 2006)(USDA-FAS 2015). While the palm oil industry brings significant economic benefits to Indonesia, the industry also burdens it with related environmental impacts. As production increases to meet the growing demand, the environmental impacts from natural or anthropogenic resource use and chemical releases also increase.

The palm oil industry has multiple potential environmental impacts on a local and global scale such as contributing to global warming, acidification, eutrophication, loss of forest land, and resource depletion (Yusoff & Hansen 2007). It is difficult to determine the most critical environmental impacts from this industry since impact categories cannot be directly compared. Moreover, the major environmental issue associated with Indonesian palm oil (IPO) production on a global scale are the greenhouse gas (GHG) emissions associated with land use changes (LUC), i.e., deforestation as the industry expands to meet growing demand. However, the Indonesian government made efforts to address these issues by implementing a moratorium policy in 2011 which has been extended two times in 2013 and 2015 (Yudhoyono & Astuti 2011)(Yudhoyono & Roesyidi 2013)(Widodo & Indrijarso 2015). Some studies have been conducted on the issue of GHG emissions associated with the palm oil industry, such as GHG emissions resulting from LUC to make way for palm oil plantations (Ramdani & Hino 2013)(Carlson et al. 2013). However, limited studies have focused on the environmental load of palm oil in Indonesia as a large producer, particularly on GHG emissions from a production supply chain process associated with a demand chain.

Over the last decade, the industry is suspected to have released significant amounts of GHG emissions that contributes to global warming and climate change (Greenpeace 2007). The efforts of the industry to reduce GHG emissions are through waste utilization as an alternative source of energy in the production process. The industry has great potential to become energy self-sufficient by utilizing their solid waste as fuel for boiler systems, briquettes, and bio-oil (through pyrolysis) and their liquid waste palm oil mill effluent (POME) for biogas (Yusoff 2006)(Poh & Chong 2009)(Abdullah & Sulaiman 2013).

Most palm oil industry in Indonesia actually have tried to apply the concept of the waste management, but their management strategies is still in the least favored option (i.e., disposal) (Stichnothe & Schuchardt 2010)(Hayashi 2007). Empty fruit bunch (EFB) is utilized conventionally as fertilizer/mulch in plantation area. POME is discharged into the pond systems for precipitation or treated for irrigation in the plantation area. Waste management related to energy recovery from palm oil wastes EFB and POME, are still not feasible to be implemented widely in the palm oil industry in Indonesia. A small scale preliminary study was conducted by Indonesian Institute of Sciences in order to evaluate the feasibility of converting EFB waste into bioethanol (Sudiyani et al. 2013). However, it still needs more efforts for mass production of bioethanol from the EFB in the near future. Furthermore, Biogas recovery from POME requires high cost for the initial investment, for instance the installation cost for the biogas generation equipment exceed US $ 3 million (Tanjung 2013). In addition, technical issues remain to be solved or answered, such how about maintenance of the pond related to desludging (Stichnothe & Schuchardt 2010). In such situation, only the fibre and shell are currently utilized in terms of waste management to generate energy (Stichnothe & Schuchardt 2010)(Hayashi 2007), and it is unknown what percentage of the IPO industry has actually applied this method.

The objectives of this study were to develop a prototype model of palm oil supply and demand chains. The model is expected to provide the basis for clarifying and estimating input and output flows in each production supply chain of the palm oil industry. In this study, the model will be used to assess the environmental load generated by the IPO industry, particularly for GHG emissions derived from LUC and energy use over the last decade (2004–2014). Finally, we evaluate the potential for waste utilization of fiber and shells to generate energy in the palm oil industry.

3.2 Model Development and Data

Basic conceptual and formal models in this study refer to an original model in chapter 2 that looked at systems from an environmental and economic perspective by connecting the supply and demand chains of palm oil (Joyosemito et al. 2014). Thus, this study is the development of a previous model.

The study model is divided into five sub-models, demand, LUC, plantation, transportation, and milling that depict the main supply and demand chains of palm oil (Figure 3-1). The demand sub-model describes the population, gross domestic product (GDP), income, consumption, and market share that influence stepwise changes in GPO demand, which eventually drives changes in the IPO industry. The other four sub-models depict the palm oil production supply chains of plantation establishment, plantation management, raw material replacement, extraction, and refinery processes. Each sub-model has a main output connecting other sub-models making it a closed model. The supply side is the fulfillment of GPO demand by the IPO industry based on their market share in the global market.

We mainly followed the tier 1 methodology of the 2006 International Panel on Climate Change (IPCC) guidelines for National Greenhouse Gas Inventories to estimate the GHG emissions resulting from LUC (IPCC 2006b) and the use of

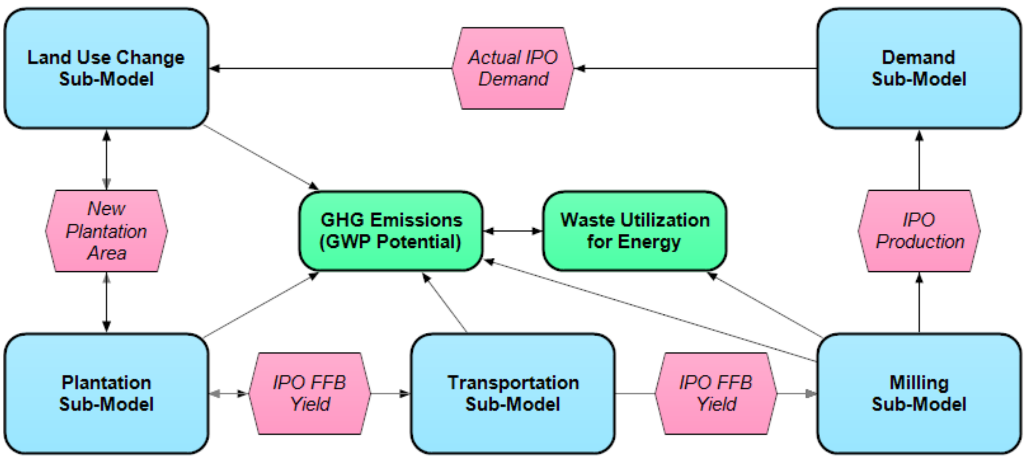


Figure 3-1. The model overview of this study developed by analytica.

fossil fuels to provide energy (IPCC 2006a). For energy production from the utilization of fiber and shells, we mainly refer to Mahlia et al. (2001). The three mostimportant GHG emissions of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) were estimated and then converted into a CO_2 equivalent (CO_2eq) to represent the global warming potential (GWP) based on 100 year atmospheric lifetimes (IPCC 2007). This study model is implemented in the Analytica Educational Professional software (Lumina Decision Systems 2015). The descriptions and mathematical models are discussed in the following sections although not all detailed model equations are presented.

3.2.1 Demand, LUC and Plantation Sub-Models

These sub-models have been decribed in the previous paper (Joyosemito et al. 2014) , and here we emphasize modifications to the sub-models. For the demand sub-model, the correlation between personal income and palm oil consumption (POC) per capita (Eq. 1) has been updated according to the historical data for the 10 year period being studied. The main output of the demand sub-model is the actual IPO demand (Eq. 2) that is the input flow for the LUC sub-model for further processing.

For the LUC sub-model, an estimation of the carbon released (in the form of CO_2; Eq. 3) is based on the establishment of new plantations located in the former tropical rainforest (TR). The CO_2 emissions is estimated by the carbon loss from each carbon pool (i.e., biomass, dead organic matter, and soils) as a result of TR conversion in a given year, following the tier 1 methodology of the IPCC guidelines for land converted to cropland. Energy input for the conversion process is not included in this study due to limited data availability.

For the plantation sub-model, an estimation of the carbon sequestration (in the form of CO_2 ; Eq. 4) is based on the change in carbon stock from each carbon pool in the plantation area, again following the tier 1 methodology of the IPCC guidelines for cropland remaining cropland. The carbon stock estimation also take into account the different age of oil palm crops on the plantation, which split into four stocks of new, immature, mature, and unproductive plantation (Joyosemito et al. 2014). The description of the four stocks is as follows.

- New plantation: the period after the conversion, the area is still under preparation for cultivation.
- Immature plantation: the period that young palm oil crops on the area are still growing, do not produce FFB yet.
- Mature plantation: the period that palm oil crops on the area reach maturity and produce FFB.
- Unproductive plantation: the period that palm oil crops on the area become old or unproductive, the growers then start to replace the unproductive crops with the new crops (replanting).

Fronds (Eq. 5) and trunks from annual pruning or felling for replanting are the main solid wastes that are generated in this production chain. It is also considered to be a carbon loss from the biomass carbon pool. Furthermore, the fresh fruit bunches (FFB) (Eq. 6) are harvested manually using hand-held tools (Pleanjai et al. 2007)(Soraya et al. 2014) and we assumed that there was no energy input for this production chain.

POC per capita(t)	= 0.00031 + [8×10^{-7} · Personal income (t)]	(Eq.1)
IPO actual demand (t)	= (GPO demand (t) × IPO market share) – IPO production (t)	(Eq.2)
LUC CO_2 emissions (t)	= (carbon stock in above-below ground biomass + carbon stock in dead organic matter + carbon stock in soils) × Area of TR converted to plantation (t) × Molecular weight ratio of CO_2 to carbon	(Eq.3)
Plantation CO_2 sequestration (t)	= [carbon stock in biomass in plantation area (t) + carbon stock in soils in plantation area (t)] × Molecular weight ratio of CO_2 to carbon	(Eq.4)
Frond waste (t)	= Mature plantation (t) × Frond from annual pruning + Frond from felling for replanting × Unproductive plantation (t)	(Eq.5)
FFB (t)	= Mature plantation (t) × FBB yield	(Eq.6)

Since this study considers only the LUC CO_2 emissions from the palm oil plantation expansion from 2004–2014, the plantation CO_2 sequestration is also from plantations established during the period for an equal condition. Simply, this study does not consider the initial conditions (t_0) of the system in the plantation sub-models for estimating the plantation carbon sequestration.

3.2.2 Transportation Sub-Model

The FFB from the plantations are transported to the milling factory for further processing to produce palm oil and this production chain activity is only a relocation process of the FFB. Thus, estimation of the energy input [terajoule (TJ), Eq. 7] is based on an assumed average distance between the plantation area and milling factory, that a pickup truck is used (basic capacity and fuel type), with an average fuel consumption per km. The released emissions (Eq. 8) are estimated following the tier 1 methodology of the IPCC guidelines for mobile combustion (MC).

Transportation energy input (t)	= FFB (t) / Truck capacity) × 2 × Average distance plantation to milling × Average fuel consumption × Net calorific value of diesel fuel	(Eq.7)
Transportation CO_2 emissions (t)	= Transportation energy input (t) × CO_2 emissions factor for MC	(Eq.8)

3.2.3 Milling Sub-Model

The process of extraction and refining in the milling factory to produce palm oil is essentially the same as previously described (Mahlia et al. 2001)(Chavalparit et al. 2006)(Hayashi 2007). We used general milling data to estimate the input–output flow being evaluated (Eqs. 9–11) which was based on the total FFB input in a given year. The released emissions from the required energy in this production chain were estimated by following the tier 1 methodology of the IPCC guidelines for stationary combustion (SC). The solid wastes that are generated are empty fruit bunches (EFB), fibres, and shells. Total IPO production is the main output of the milling sub-model that acts as a feedback connecting the supply and demand chain of palm oil. Thus, the actual demand for IPO (see Eq. 2) is a balancing process between GPO demand, IPO market share, and total IPO production.

Milling energy input (t)	= FFB (t) × (Electricity energy consumption + Diesel fuel energy consumption)	(Eq.9)
Milling CO_2 emissions (t)	= Milling energy input (t) × CO_2 emissions factor for SC	(Eq.10)
Fibre waste (t)	= FFB (t) × $\text{Fibre}_{\text{ratio to FFB}}$	(Eq.11)

$$\text{IPO production (t)} = \text{FFB yield(t)} \cdot (\text{CPO}_{\text{ratio to FFB}} + \text{CPKO}_{\text{ratio to FFB}}) \quad \text{(Eq.12)}$$

3.2.4 Data and Simulation

Data for this model were derived from secondary data collection. Driving force data (population, GDP, consumption) that influences changes in palm oil demand were mainly obtained from the World Bank (World Bank 2015) and the United State Department of Agriculture, Foreign Agricultural Service (USDA-FAS 2006, 2015, 2009, 2012). Data related to area and production of IPO were obtained from Badan Pusat Statistik Indonesia (BPS-Indonesia 2011, 2015). Since data related to the elementary flows of the processes within the palm oil production supply chains in Indonesia were limited, this study used a combination of data collected from previous studies throughout Southeast Asia.

The model is a simplification of a real system, then to represent the real system that is full of uncertainty, such as unstable economic conditions and technological change in the production process, some data inputs for the model use a normal distribution (mean, standard deviation). Thus, the model output of this study does not only reveal a deterministic value but also an uncertain value. All input data for the model are listed in Table 3-1.

Simulations were run from 2004–2014 at one year intervals. Monte Carlo simulations were run simultaneously to deal with uncertainty sources in the model such as model structure and data inputs. Thus, the model output that is shown in this study is the mean of the uncertain values which were estimated using 2000 random samples of the entire model.

3.3 Result and Discussion

3.3.1 Model Validation

We established, on the basis of a real data system and unrealistic conditions, confidence that the model is reasonable, realistic, and useful for the system being studied. To achieve this, we conducted historical reproductions and extreme conditions testing.

Table 3-1. Input data for model simulation.

No.	Variable	Value	Data Source
1	World population 2004	6412467468 people	(World Bank 2015)
2	Population growth rate	Normal (1.2, 0.03) %	
3	World GDP 2004	43.5×10^{12}USD	
4	GDP nominal growth rate	Normal (6.7, 5.6) %	
5	IPO market share	Normal (48.2, 3.7) %	(USDA-FAS 2006)(USDA-FAS 2015)(USDA-FAS 2009)
6	IPO productivity	Normal (3.1, 0.2) Mg ha^{-1}	(USDA-FAS 2006)(USDA-FAS 2015)(USDA-FAS 2009) (BPS-Indonesia 2011)(BPS-Indonesia 2015)
7	Immature plantation 2004	1715459 ha	(BPS-Indonesia 2011)
8	Mature plantation 2004	3935981 ha	
9	Unproductive plantation 2004	65586 ha	
10	Transition time of TR to new plantation	1 year	(Corley & Tinker 2003)
11	Transition time of new to immature plantation	1 years	
12	Transition time of immature to mature plantation	1.75 years	
13	Productive time (mature to unproductive plantation)	Normal (25, 3.3) years	(Yusoff & Hansen 2007)(Abdullah & Sulaiman 2013)(Soraya et al. 2014)(Ling 2012)
14	TR above-ground biomass	350 Mg d.m ha^{-1}	(IPCC 2006b)
15	TR ratio of below to above-ground biomass	0.37 Mg root d.m. (Mg shoot d.m.)$^{-1}$	
16	TR Litter and dead wood carbon stocks	5.2 Mg C ha^{-1}	
17	Reference carbon stock	86 Mg C ha^{-1}	
18	TR stock change factor for land-use system, management regime system and input of organic matter	1 (dimensionless)	
19	Emission factor for drained organic soils	1.36 Mg C ha^{-1} $year^{-1}$	
20	Carbon stock in biomass one year immediately following conversion	10 Mg C ha^{-1} $year^{-1}$	
21	Cropland stock change factor for land-use system and input of organic matter	1 (dimensionless)	
22	Cropland stock change factor for management regime system	1.22 dimensionless)	
23	Emission factor for cultivated organic soils	20 Mg C ha^{-1} $year^{-1}$	

Table 3-1. Input data for model simulation (continued).

No.	Variable	Value	Data Source
24	Default value carbon fraction of dry matter	0.47 Mg C (Mg d.m.)$^{-1}$	(IPCC 2006b)
25	Molecular weight ratio of CO_2 to carbon	44/12	(IPCC 2006b)
27	Frond from annual pruning	10.4Mg d.m ha^{-1}	(Yusoff 2006)
28	Frond from felling for replanting	14.4 Mg d.m ha^{-1}	(Yusoff 2006)
29	Trunk from felling for replanting	75.5Mg d.m ha^{-1}	(Yusoff 2006)
30	FFB yield	Normal (17, 2.2) Mg ha^{-1} year^{-1}	(Yusoff & Hansen 2007)(Yusoff 2006)(Chavalparit et al. 2006)
31	Average distance plantation to milling	1.5 km	(Pleanjai et al. 2007)
32	Truck capacity	3 Mg	(Pleanjai et al. 2007)
33	Transportation diesel fuel consumption	0.667 L Km^{-1}	(Pleanjai et al. 2007)
34	CO_2 emissions factor for MC	74.1 Mg TJ^{-1}	(IPCC 2006a)
35	N_2O emissions factor for MC	0.0013 Mg TJ^{-1}	(IPCC 2006a)
36	CH_4 emissions factor for MC	0.0039 Mg TJ^{-1}	(IPCC 2006a)
37	Net calorific value of diesel fuel	0.043 TJ Mg^{-1}	(IPCC 2006a)
38	CO_2 emissions factor for SC	74.1 Mg TJ^{-1}	(IPCC 2006a)
39	N_2O emissions factor for SC	0.0006 Mg TJ^{-1}	(IPCC 2006a)
40	CH_4 emissions factor for SC	0.003 Mg TJ^{-1}	(IPCC 2006a)
41	Milling diesel fuel energy consumption	Normal (0.78, 0.54) L (Mg FFB)$^{-1}$	(Yusoff & Hansen 2007)(Yusoff 2006)(Chavalparit et al. 2006)(Hayashi 2007) (Pleanjai et al. 2007)(Soraya et al. 2014)
42	Milling electricity energy consumption	Normal (15.2, 1.9) kWh (Mg FFB)$^{-1}$	(Yusoff & Hansen 2007)(Yusoff 2006)(Chavalparit et al. 2006)(Hayashi 2007) (Pleanjai et al. 2007)(Soraya et al. 2014)
43	$EFB_{ratio\ to\ FFB}$	Normal (0.251, 0.031)	(Yusoff & Hansen 2007)(Yusoff 2006)(Chavalparit et al. 2006)(Hayashi 2007) (Pleanjai et al. 2007)(Soraya et al. 2014)
44	$Fibre_{ratio\ to\ FFB}$	Normal (0.141, 0.01)	(Yusoff & Hansen 2007)(Yusoff 2006)(Chavalparit et al. 2006)(Hayashi 2007) (Pleanjai et al. 2007)(Soraya et al. 2014)
45	$Shell_{ratio\ to\ FFB}$	Normal (0.064, 0.009)	(Yusoff & Hansen 2007)(Yusoff 2006)(Chavalparit et al. 2006)(Hayashi 2007) (Pleanjai et al. 2007)(Soraya et al. 2014)
46	$CPO_{ratio\ to\ FFB}$	Normal (0.197, 0.022)	(Yusoff & Hansen 2007)(Yusoff 2006)(Chavalparit et al. 2006)(Hayashi 2007) (Pleanjai et al. 2007)(Soraya et al. 2014)
47	$CPKO_{ratio\ to\ FFB}$	Normal (0.058, 0.005)	(Yusoff & Hansen 2007)(Yusoff 2006)(Chavalparit et al. 2006)(Hayashi 2007) (Pleanjai et al. 2007)(Soraya et al. 2014)
48	Fibre net calorific value	11.324x10^{-3} TJ Mg^{-1}	(Mahlia et al. 2001)
49	Shell net calorific value	17.516 x10^{-3} TJ Mg^{-1}	(Mahlia et al. 2001)
50	Efficiency of energy conversion for fibre and shell	68%	(Mahlia et al. 2001)
51	CO_2 emissions factor for Fibre combustion	1.73 Mg (Mg Fibre)$^{-1}$	(Mahlia et al. 2001)
52	CO_2 emissions factor for Shell combustion	1.92 Mg (Mg Shell)$^{-1}$	(Mahlia et al. 2001)
53	CO_2 GWP	1 CO_2eq	(IPCC 2007)
54	CH_4 GWP	25 CO_2eq	(IPCC 2007)
55	N_2O GWP	198 CO_2eq	(IPCC 2007)

3.3.1.1 Historical Reproduction Testing.

Reproduction data testing was conducted for three key variables, GPO demand, IPO plantation area, and IPO production. All were considered to be important variables for constructing the model. The coefficient of determination (R^2) and the mean absolute percent error (MAPE) were used to assess the proportion of total variation and accuracy of the data that were replicated by the model.

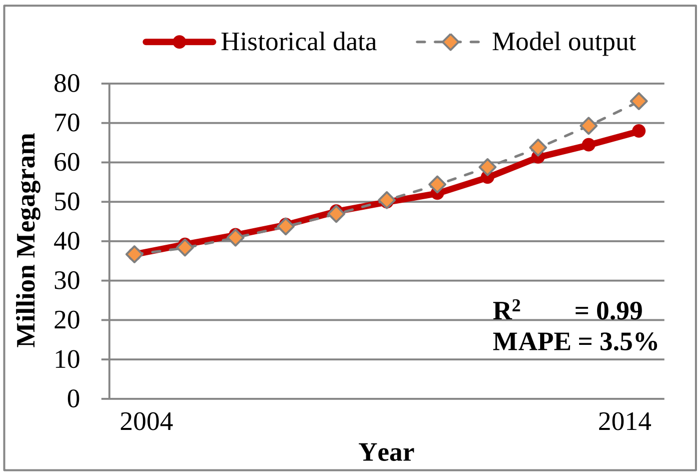
A comparison of historical data and model output from 2004–2014 for the three variables are shown in Figure 3-2. The results show that the model output corresponds well with the historical data because R^2 and MAPE for all three variables are close to 1 and < 10%, respectively. This indicates that the model is able to reproduce the essential structure of the supply and demand chain of palm oil in a real system and might have good predictive power to estimate the environmental load generated by IPO production chain activities.

3.3.1.2 Extreme Condition Testing

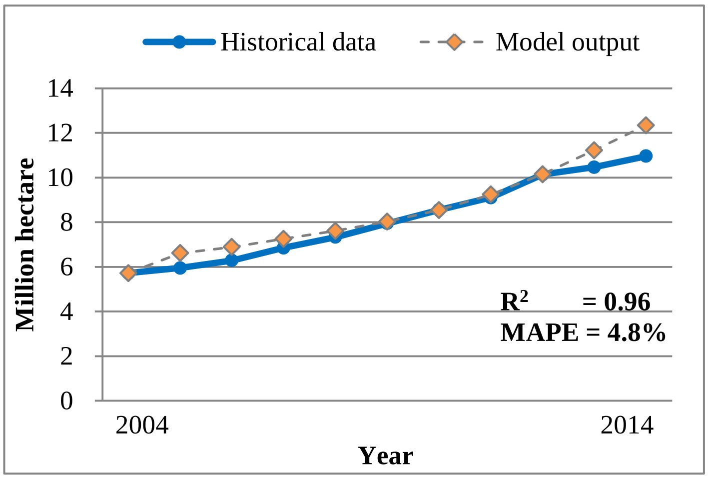
An accurate model should work plausibly under all conditions and extreme condition testing for this model focused on the main factors (in the demand sub-model) that drive changes in the IPO industry. The extreme condition for this test was, starting from 2009, the GDP remaining constant at the 2008 level until 2014. That is, we determined the effect of zero change in the GDP during this period.

The purpose of this testing was to isolate the effect of the driving factor. Thus, there should not be an increase in GPO demand from 2008–2014 (Figure 3-3.a). Furthermore, the stock of total GHG emissions also corresponded with the pattern and became more stable (Figure 3-3.b). The model demonstrates that it produces realistic outputs under extreme input values (in this case, zero change).

a. Global palm oil demand.



b. Indonesian palm oil plantation area.



c. Indonesian palm oil production.

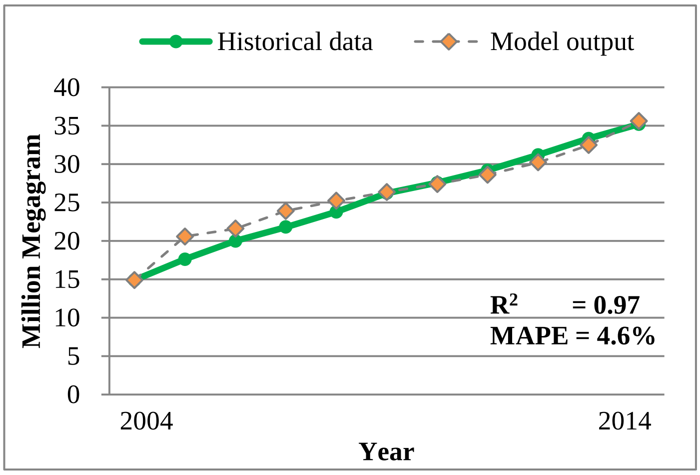
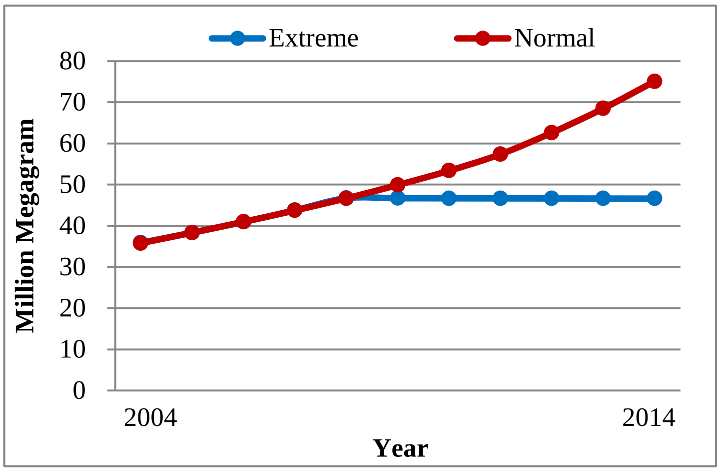


Figure 3-2. The result of reproduction data testing of the model.

a. Global palm oil demand.



b. Stock of total GHG emissions.

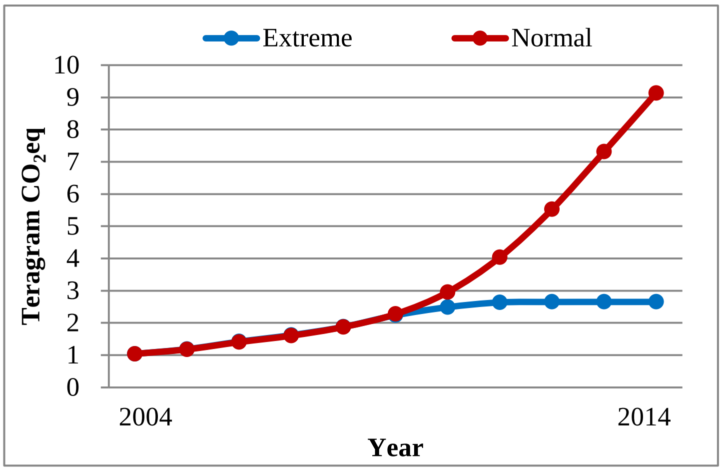


Figure 3-3. The result of extreme condition testing of the model.

3.3.2 Environmental Load of the Indonesian Palm Oil Industrial Sector.

The simulation results for the input–output flow of the IPO industry for the last decade are presented in a combination of tabular and graphical forms (Figure 3-4). The GPO demand was, on average, 51 million Mg/year from 2004–2014. Considering the IPO's market share and production, the actual demand for IPO was approximately 2.3 million Mg/year. Thus, conversion of forests to palm oil plantations has occurred at an average pace of 0.75 million ha/year over the last decade. In 2014, the IPO industrial sector had a total mature plantation area twice as large as that in 2004. It was predicted that it could yield an average of 100.8 million Mg/year of FFB. Hence, the IPO industrial sector was able to produce 25.4 million

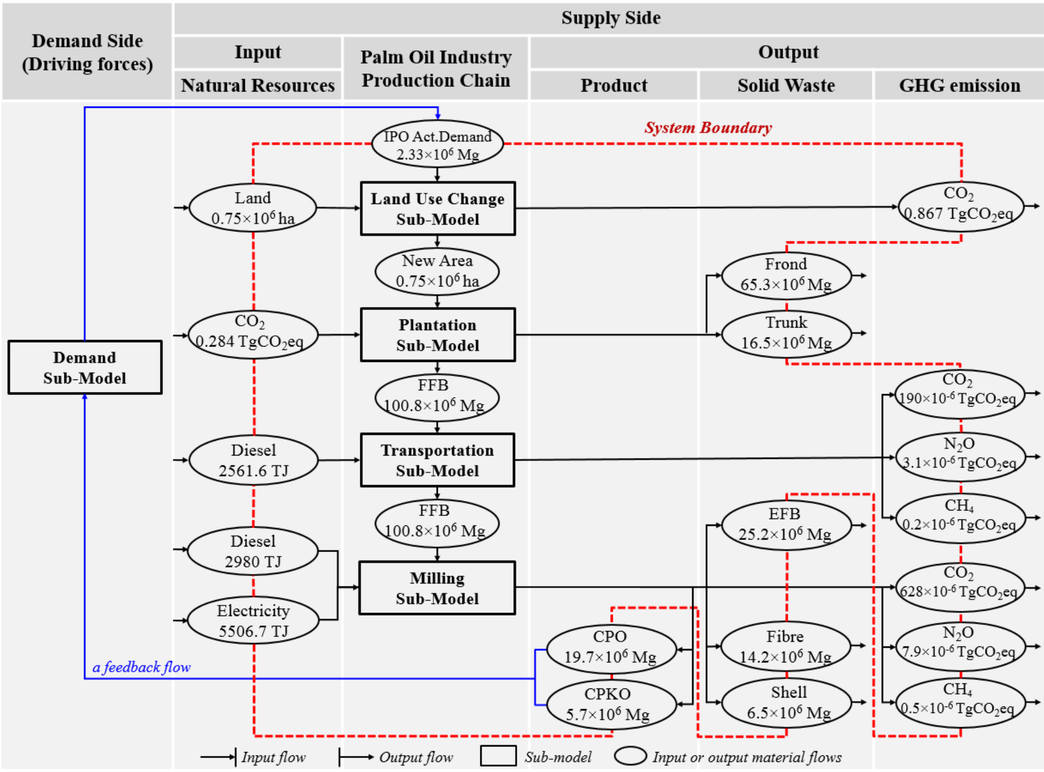


Figure 3-4. The average environmental load per year of the palm oil industry sector in Indonesia for the time period 2004–2014.

Mg/year of palm oil during 2004–2014. According to this level of production, the environmental loads due to energy, gas emissions, and solid wastes during 2004–2014 are as follows.

The total energy input used (i.e., required energy) by the IPO industrial sector was, on average, approximately 11048 TJ/year during 2010–2020, with 2562 TJ/year and 8486 TJ/year for transportation and milling chains, respectively. Thus, 434 MJ of energy is required to produce 1 Mg of palm oil.

The GHG emissions released by the IPO industrial sector were primarily from the LUC chain (0.867 Tg CO_2eq/year), followed by milling (636.6×10^{-6} Tg CO_2eq/year) and transportation chains (192.9×10^{-6} Tg CO_2eq/year). The IPO industrial sector generated total GHG emissions of approximately 0.868 Tg/year during the period 2004–2014. In contrast, the carbon sequestrations in the plantation production chain were also quite high at approximately 0.284 Tg CO_2eq/year. This is from carbon accumulation, in line with the growth of palm oil crops in the plantation areas. Thus, net GHG emissions that were emitted to the atmosphere were approximately 0.584 Tg CO_2eq/year.

Total solid wastes in terms of the weight generated by the IPO industrial sector were 127.7 million Mg/year. The breakdown is 65.3, 16.5, 25.2, 14.2, and 6.5 million Mg/year for frond, trunk, EFB, fiber, and shells, respectively. Thus, for each Mg of palm oil produced, another 5 Mg of solid waste is generated.

Figure 3-5 depicts changes in the stock of GHG emissions in the atmosphere (i.e., GWP) that cumulatively balance between annual (flow) GHG emissions and carbon sequestration as a result of the IPO production chain activities during 2004–2014. The model demonstrates that the plantation production chain also serves as an important source of carbon sequestration for the palm oil industry that affects GHG emission cycles. Until 2014, the stock (total) of GHG emissions and carbon sequestration resulted from the IPO production chain activities are 9.5 and 3.1 Tg CO_2eq, respectively. Thus, carbon sequestration in the plantation production chain contributed to reduce the GWP (6.4 Tg CO_2eq) by nearly one-third based on total GHG emissions. The fast growing palm oil crops that become mature within three years is the main reason for this significant carbon repayment. Furthermore, it should be noted that this rapid growth also increases mature crops, which implies an increasing FFB yield and palm oil production. Therefore, the ratio of net GHG emissions released relative to the amount of palm oil produced actually decreased

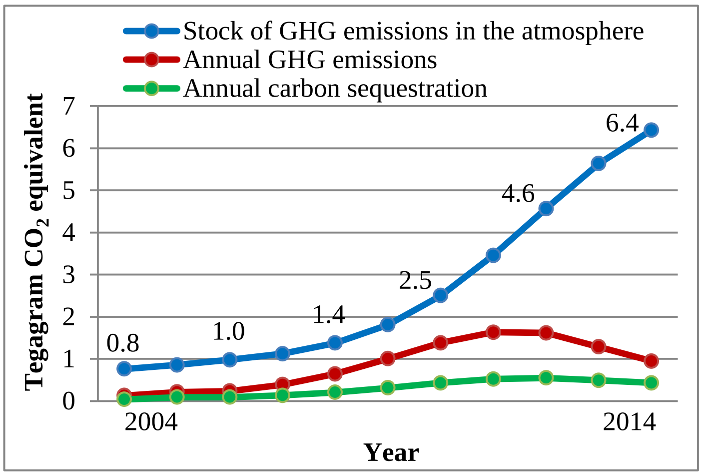


Figure 3-5. Global warming potential of the IPO industrial sector for the time period 2004-2014.

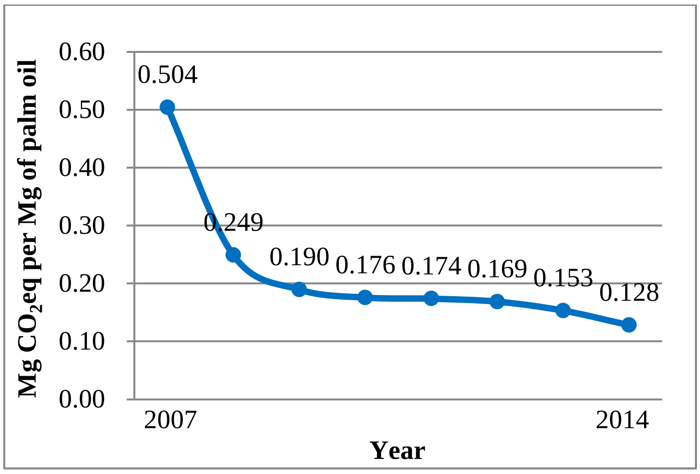


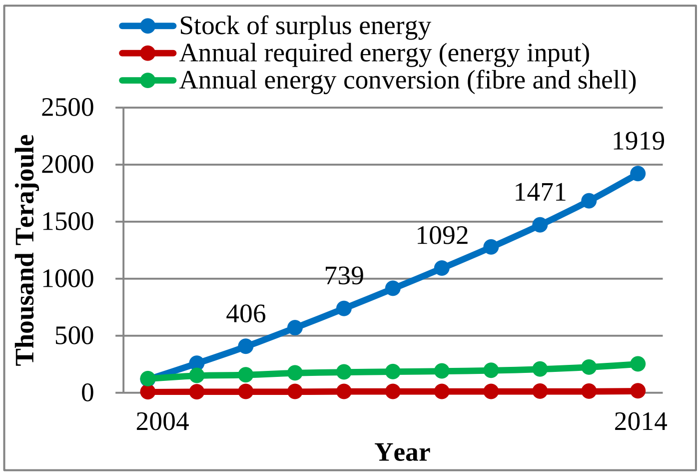
Figure 3-6. Illustration for the GHG intensity changes of palm oil.
As described previously, this study considers only the LUC CO_2 emissions from the palm oil plantation expansion from 2004–2014, the plantation CO_2 sequestration is also from plantations established during the period for an equal condition. Thus, the illustration for the GHG intensity of palm oil is also based on palm oil production from the plantation established during the period. Simply, the illustration above does not consider the initial conditions (t_0) of mature plantations. The palm oil production from 2004 to 2005 is still zero because about three years are required for the establishment and management processes of the palm oil plantation until the palm oil crops to reach maturity and produce FFB. Hence, GHG intensity of palm oil cannot be calculated during the period 2004 to 2006.

over time. Figure 3-6 illustrates changes in the GHG intensity of palm oil over time. The GHG intensity of palm oil was high in the initial establishment of a plantation area and then continued to decline as the plantation became well established. Under this simulation, the GHG intensity of palm oil was in the range 0.5–0.13 Mg CO_2eq per Mg of palm oil.

3.3.3 Waste utilization to generate energy

As mentioned previously, one of environmental loads is solid waste which has the potential to generate energy. Hence, we estimated the energy generated from solid waste, specifically from fibre and shells. Simulations were conducted to estimate and obtain an overview of the energy conversion from fiber and shell wastes including GHG emissions as a result of the process. Under this simulation, it was assumed that all fibre and shells generated by the IPO industrial sector (20.7 million Mg/year) were utilized as a fuel for boiler systems to generate energy (i.e., energy conversion) and the energy balance input required by the IPO industrial sector was determined.

a. Surplus energy from fibre and shell utilization in the IPO industrial sector.



b. Amount of fibre and shell to balance the required energy in the IPO industrial sector.

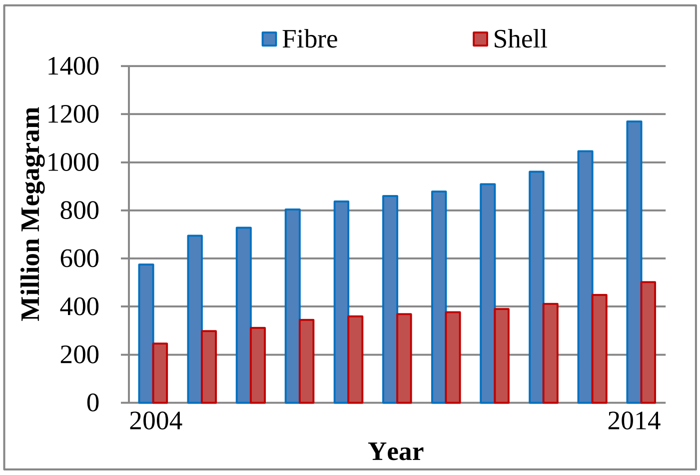


Figure 3-7. Simulation results of fibre and shell utilization for energy.

Figure 3-7.a illustrates the surplus energy from fibre and shell utilization in the IPO industrial sector. The potential energy conversion from fiber and shells was approximately 1.9×10^5 TJ/year, while the annual energy surplus was estimated to reach 1.7×10^5 TJ/year. Thus, the cumulative energy surplus reached 1.9×10^6 TJ in 2014. It should be emphasized that this illustration was only from the utilization of 16.2% of the solid wastes generated by the IPO industrial sector/year. The amount of fiber and shell needed to balance the required energy in the IPO industrial sector was 8.6×10^5 and 3.7×10^5 Mg/year, respectively (Figure 3-7.b). The emissions produced as a result of the energy conversion process were 2.2×10^{-3}

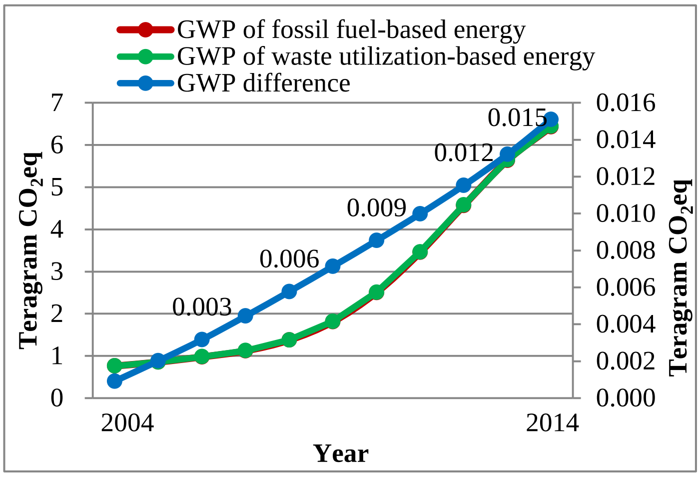


Figure 3-8. Global warming potential of the IPO industrial sector using a different energy source.

or 2.4×10^{-2} Tg CO_2eq cumulatively up to 2014.

Figure 3-8 depicts a comparison of the GWP resulted from the IPO production supply chain activities using a different energy source (i.e., fossil fuels and waste utilization). The model simulation shows that the GHG emissions from fossil fuels were lower than the waste fuel-based energy within the production supply chain boundary used in this study. However, there was not much difference in GHG emissions between fossil fuel-based and waste fuel-based energy when it came to GWP calculations. This implies that waste utilization to generate energy is still a promising replacement for fossil fuels, and it also reduces the environmental load, particularly within larger boundaries which involve fugitive emissions.

3.4 Conclusion

This study presents the development of a prototype model of the palm oil supply and demand chains for the historical reconstruction of GHG emissions from the IPO industry based on the tier 1 methodology of the 2006 IPCC guidelines for National Greenhouse Gas Inventories. The following conclusions were made based on the practical application of our model.

The environmental load related to the input-output of land, raw materials (FFB), energy, GHG emissions, and solid wastes were analyzed by the model. The model demonstrated that when LUC was initiated to establish plantation areas, the

GHG intensity was high. Established plantations drive carbon sequestration and increasing production that resulted in a gradual decrease in GHG intensity over time. Hence, the plantation production supply chain played an important role in the natural balance of GHG emissions released by the palm oil industry.

Within the boundary of this study, we revealed that the use of waste fuel-based energy released higher GHG emissions compared with the use of fossil fuel-based energy. However, within a larger boundary (including the fugitive emission), the opportunity to maximize the utilization of waste to generate energy is still a promising option for reducing future environmental loads.

The prototype model successfully represented the essential structure of the real system and worked plausibly under all input conditions. Thus, the model should be applicable for assessing other environmental loads associated with the palm oil industry, although some case dependent adjustments may be necessary.

Further work is needed to extend the framework for estimating the environmental loads of the palm oil industry which have impacts on human health. For example, the extensive use of agricultural chemicals in the industry including paraquat and glyphosate should be investigated. *Under simulation of our model, the estimated total Paraquat and Glyphosate that have been applied by IPO industrial sector during 2004-2014 is about 36177 and 47232Mg/year, respectively. Or, both Paraquat and Glyphosate that have been released to the environment is about 917500 Mg cumulatively in total until 2014.* Hence, the fate, transport, and effects of these substances in the multiple environmental media should be clarified.

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CHAPTER 4

A MODELING APPROACH TO STUDY THE PESTICIDE DYNAMICS TO REDUCE PESTICIDE RESIDUES IN JAPANESE GREEN TEA

4.1 Introduction

Concerns about food safety are increasing globally. One major concern is the use of pesticides on crops. The maximum residue limit (MRL)[2)] is a value that is set to ensure the use of a pesticide such that consumer health will not be harmed. The MRL value defines the maximum concentration of pesticide residue legally permitted in food or feed commodities and is applied through the good agriculture practice (GAP) guidelines (Bates 2002)(MacLachlan & Hamilton 2010). GAP was established to satisfy several objectives; one of which is to ensure the safety and quality of products in the food chain (FAO 2008).

A food commodity for which pesticide residues are of particular concern is tea. As tea is a popular beverage worldwide, there is a possibility that many people are exposed to pesticide residues through drinking tea. As awareness of this issue is increasing, many countries are taking action by setting their own tentative limits for pesticide residues in tea, or by adopting the default MRL values set by international organizations such as the Codex Alimentarius Commission (CAC), or by establishing more stringent MRLs based on their own studies (Jaggi et al. 2001) (Huang et al. 2007). Conversely, MRLs are also major constraints for tea-exporting countries in marketing their tea, especially for exporters from the least-developed countries (Gurusubramanian et al. 2008) (FAO 2014).

Tea, particularly green tea, is a common beverage in Japan and has also been part of food culture among people for centuries. Although Japan is an exporter of green tea, its products cannot be shipped to certain European countries. This is because some pesticide residues are higher than the MRL standards set by CAC and European Union (EU). Therefore, more attention to the management of tea plantations by application of GAP is needed. The challenge for tea plantation management is identifying methods to produce good and safe fresh tea leaves, while using pesticides intensively to reduce yield losses and plant toppling caused by pests and diseases (e.g., plant-parasitic nematodes, insect pests, and pathogenic fungi). With the use of pesticides, an appropriate implementation of GAP in tea plantations plays an important role in decreasing chemical contamination in green tea. Hence, it is crucial to study the MRL values and application of GAP in tea plantation areas in order to reduce the constraints in exporting to other countries.

Supervised field trials are conducted to quantify and determine the pesticide residue and MRL values for tea. To summarize, experiments are conducted in tea plantation areas according to GAP, pesticides are applied based on the dosage forms, and tea samples plucked after an appropriate time interval (i.e., the pre-harvest interval; PHI) are analyzed in laboratory tests. Finally, all trial data that are considered to be valid are considered for setting of MRL (FAO 2005) (Seenivasan & Muraleedharan 2009) (EFSA 2012). However, these steps are time-consuming and costly. Using models that represent some important aspects of the real system, it may be possible to improve our understanding of how to manage the application of GAP to meet the expected pesticide residue levels such that the MRL values can satisfy CAC and EU standards.

The aim of this study is to develop a modeling approach to clarify and estimate the exposure pathways of pesticides on a tea plantation using a case study in Shizuoka, Japan, and finally to propose an improvement to the Japanese GAP.

4.2 Method and Modeling Process

4.2.1 Model Construction.

Model development in this study uses the compartmental mass-balance concept (Trapp & Matthies 1998). We adopt and simplify the United States Environmental Protection Agency (USEPA) conceptual model of pesticide effects on terrestrial organisms (USEPA 2011). Figure 4-1 depicts the structural relationships between the elements that may relevant to and sufficient for the representation of the real system being studied. The model is divided into sub-models of tea plant developmental stages and pesticide fate and transport. The conceptual models are subsequently formalized in the quantitative model. We mainly refer to the studies of Trapp and Matties (1995), Fantke and Juraske (2013), Fantke et al. (2014a) for the formulation of the pesticide fate and transport sub-model. The model of this study is implemented in Analytica Software: further details about the software are provided in Lumina Decision Systems (2015). The descriptions and mathematical models corresponding to the structural relationships (Figure 4-1) are discussed in the following sections (the indices and symbols of the mathematical equations are listed in Table 4-1).

4.2.1.1 Sub-model of Tea Plant Developmental Stages.

The amount of applied pesticide is assumed relative to the tea plant growth stage, the main developmental stages of tea plants in Japan are as follows.

- Tea seedlings are usually transplanted to the plantation area when they are two years old. Furthermore, branch formation (by pruning) begins in the second year after the fixed planting of the tea seedlings in the plantation area. Pruning is conducted to curb the height of the main trunk and promote the growth of lateral branches (ITOEN 2015). Thus, the total time required for a new seedling to become an immature tea plant is approximately four years.
- From fixed planting of the tea seedlings in the plantation area, four to eight years are required for the plants to reach maturity and become suitable for commercial exploitation (ITOEN 2015). Although it is possible to harvest the tea leaves from the fourth year, harvesting in the fifth year will provide a more stable yield and better quality (WGTA 2015a). Thus, an immature tea plant requires three years (five years minus the two-year seedling stage) to become a mature plant.
- The productive time of a mature tea plant is limited by its lifetime. In Shizuoka's plantation, the lifetime of tea plants has been determined to be 34 years (Shizuoka Prefecture 2014). Thus, the productive time of mature tea plants is approximately 27 years (34 years of life minus seven years required to reach maturity).

On the basis of this description, we divide the area of the tea plantation into three main compartments, i.e., new (table 2 no.1), immature (table 2 no.2), and mature/productive (table 2 no.3), which describe the developmental stages of tea plants based on their age. Thus, the total area (table 2 no.4) of the tea plantation is

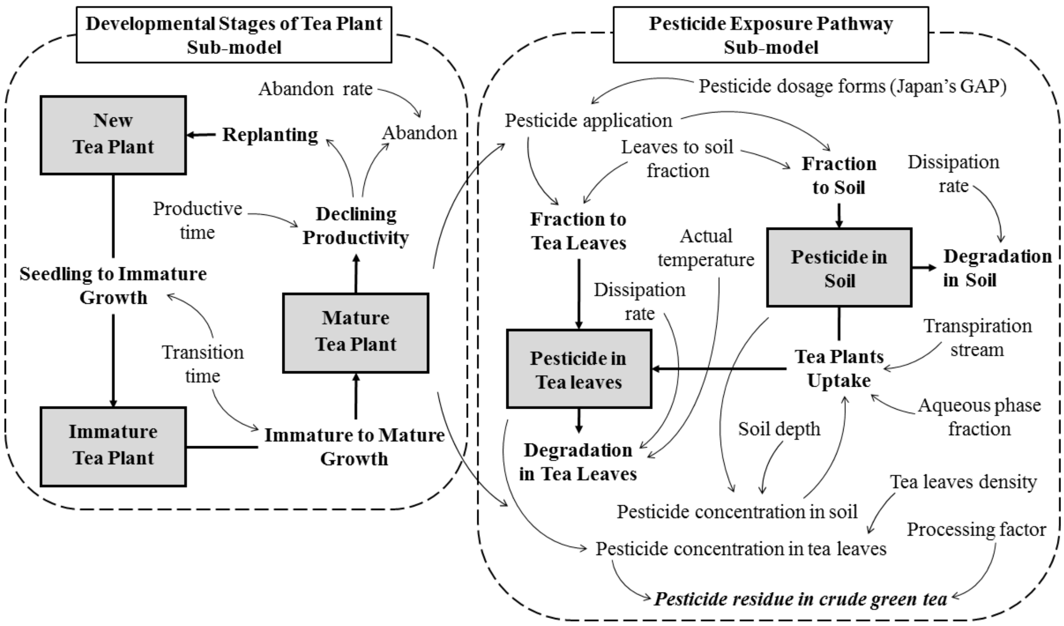


Figure 4-1. The model of this study.

defined by the summation of these three compartments. Furthermore, the management of a tea plantation is assumed to be a cyclical and repeating pattern, i.e., after the tea plants have reached their maximum productive time (aging tea plant), they will be removed and the area will then be replanted (table 2 no.10), with the exception of old tea plants that are not replanted (the area is abandoned).

4.2.1.2 Pesticide Fate and Transport Sub-model.

The pesticide fate and transport sub-model is split into soil and tea leaves compartments, which describe the movement and transformation of pesticides in the tea plantation area. During the directed spray application of pesticide over the tea plantation, the two compartments are assumed to be directly exposed; thus, each compartment potentially receives a fraction of the applied pesticide. The fraction splits the applied pesticide into two flows that enter the soil and tea leaves compartments. Some of the fraction that enters the soil compartment can flow to the tea leaves compartment through absorption by the roots of tea plants, and some the rest is degradated.

The dynamic mass balance quantitative model for pesticide in the soil compartment (m_{soil} ; table 2 no.9) is assumed to be controlled by a fraction of the applied pesticide that flows to the soil (table 2 no.12), the uptake of pesticide by tea plants and the complex chemical process in the soil. Terrestrial plants have a similar basic structure, comprising roots, stems, and leaves: pesticides in polluted soils are absorbed by the roots, transported to the stem, and eventually deposited in the leaves. According to (Trapp & Matthies 1998) the processes of uptake by tea plants (table 2 no.13) depend on transpiration stream (Q), mature tea plant, pesticide concentration in soil water ($C_{soil\text{-}water}$) and transpiration stream concentration factor. $C_{soil\text{-}water}$ is estimated by concentration of pesticide in the soil (C_{soil}) and dissolved fraction of the pesticide in the aqueous phase. C_{soil} (table 2 no.17) is estimated by m_{soil} per volume of the mature tea plant area, the unit for this quantity is kilograms (kg) per cubic meter (m^3). Many chemical reactions or radioactive decay are usually represented by the amount of time required for the activity to fall to half of its initial value (half-life; $t_{1/2}$); these processes follow an exponential decay equation of the first order (Trapp & Matthies 1998) (Fantke & Juraske 2013). Thus, the complex chemical process that degradate pesticide in the soil (table 2 no.14) are estimated by m_{soil} and the pesticide dissipation half-life in soil.

Similarly to the soil compartment, the dynamic mass balance quantitative model for pesticide in the tea leaves compartment ($m_{tea\ leaves}$; table 2 no.11) is assumed to be controlled by the fraction of the applied pesticide that flows into the tea leaves (table 2 no.12), pesticide uptake from soil (tea plant uptake, as described in the soil compartment; table 2 no.14), and the complex chemical processes in the tea leaves. The complex chemical processes that degrade pesticides in the tea leaves (table 2 no.16) are estimated by $m_{tea\ leaves}$ and the pesticide dissipation half-life that is estimated from the pesticide properties, plant characteristics, and temperature (Fantke et al. 2014a). Furthermore, it is assumed that the pesticide and tea leaves in this compartment are proportional, and then the pesticide concentration in tea leaves ($C_{tea\ leaves;}$ table 2 no.18$_{)}$ is estimated from the total biomass of tea leaves in the mature tea plant area. Thus, the pesticide residue in crude green tea ($C_{green\ tea}$; table 2 no.19) is estimated from $C_{tea\ leaves}$ and the average processing factor for the production of crude green tea ($Pf_{green\ tea}$), with units of milligrams (mg) of the pesticide substance per kg of the crude green tea. The processing factor is defined as the ratio of the pesticide residue in the processed commodity to the residue in the raw commodity before processing (FAO 2009).

Table 4-1. Model formulas.

No.	Variable	Equation
Sub-model of tea plant developmental stages		
1	Total tea plant(t)	= New tea plant(t) + Immature tea plan(t) + Mature tea plant(t)
2	New tea plant(t)	$= \text{Initial new tea plant} + \int_{t0}^{t} \text{Replanting}(s)ds - \int_{t0}^{t} \text{Seedling to immature growth}(s)\ ds$
3	Immature tea plant(t)	$= \text{Initial immature tea plant} + \int_{t0}^{t} \text{Seedling to immature growth}(s)ds - \int_{t0}^{t} \text{Immature to mature growth}(s)ds$
4	Mature tea plant(t)	$= \text{Initial mature tea plant} + \int_{t0}^{t} \text{Immature to mature growth}(s)ds - \int_{t0}^{t} \text{Declining productivity}(s)ds$
5	Replanting(t)	= Declining productivity(t) – Total plant(t) × Abandon rate
6	Seedling to immature growth(t)	= New tea plant(t) / Transition time of seedling to immature
7	Immature to mature growth(t)	= Immature tea plant(t) / Transition time of immature to mature
8	Declining productivity(t)	= Mature tea plant(t) / Productive time
Pesticide fate and transport sub-model		
9	Pesticide in soil, $m_{soil}(t)$	$= \text{Initial pesticide in soil} + \int_{t0}^{t} \text{Fraction pesticide to soil}(s)ds - \int_{t0}^{t} \text{Tea plant uptake}(s)ds - \int_{t0}^{t} \text{Pesticide Degradation in soil}(s)ds$
11	Pesticide in the tea leaves, $m_{tea\ leaves}(t)$	$= \text{Initial pesticide in tea leaves} + \int_{t0}^{t} \text{Fraction pesticide to tea leaves}(s)ds + \int_{t0}^{t} \text{Tea plant uptake}(s)ds - \int_{t0}^{t} \text{Pesticide Degradation in tea leaves}(s)ds$
12	Fraction pesticide to soil(t)	= Pesticide dosage forms × Mature tea plant(t) × (1 − Leaves to soil fraction)
13	Tea plant uptake(t)	$= \frac{Q \times \text{Mature tea plant}(t) \times C_{Soil}(t) \times \text{Soil}_{pore}}{(K_{OC} \times OC \times D_{soil} \times 10^{-3}) + \text{Soil}_{pore} + (\text{Soil}_{porosity} - \text{Soil}_{pore}) \times K_{AW}} \times 0.784 \exp \frac{-(\log K_{OW} - 1.78)^2}{2.441}$

Table 4-1. Model formulas (continued).

No.	Variable	Equation
	Pesticide fate and transport sub-model	
14	Pesticide degradation in soil(t)	$= \frac{m_{soil}(t) \times \ln(2)}{t_{1/2\ soil}}$
15	Fraction pesticide to tea leaves(t)	= Pesticide dosage forms × Mature tea plant (t) × Leaves to soil fraction
16	Pesticide degradation in tea leaves(t)	$= \frac{m_{tea\ leaves}(t) \cdot \ln(2)}{10^{[\alpha + \beta_{pesticide} + \beta_{tea\ plant} + \beta_T (T - T_{ref})]}}$
17	Pesticide concentration in soil, $C_{soil}(t)$	$= \frac{m_{soil}(t)}{\text{Mature tea plant}(t) \cdot \text{Soil depth}}$
18	Pesticide concentration in tea leaves, $C_{tea\ leaves}(t)$	$= \frac{m_{tea\ leaves}(t)}{\text{Mature tea plant}(t) \cdot \text{Tea leaves biomass}}$
19	Pesticide residu in crude green tea, $C_{green\ tea}(t)$	$= C_{tea\ leaves}(t) \times Pf_{green\ tea}$

4.2.2 Test Agricultural Chemicals

There is an agreement that World Trade Organization (WTO) members have their right to determine their own MRL (Randell 2000). Thus, there is a lack of global harmonization in fixing the MRL values (FAO 2005). It is because there are differences in procedures to determine MRL in each country, such GAP and residue definition for dietary intake assessment. Hence, it makes different MRL standard among countries

From our literature survey and data availability, six chemicals were focused on, i.e., Azoxystrobin, Chlorfenapyr, Clothianidin, Etoxazole, Spiromesifen, and Thiacloprid (Table 4-2). On the basis of the Japanese MRLvalues, two types of pesticide should be considered, because they have different threshold values in the Japanese, CAC, and EU MRLs. These two pesticides are Clothianidin and Azoxystrobin, which have Japanese MRL values that are larger than those of the CAC and EU. The MRL for Clothianidin in Japan is 50 mg/kg while the value for CAC and the EU is 0.7 mg/kg. For Azoxystrobin, the value for Japan is 10 mg/kg and that of the EU is 0.1 mg/kg (JFCRF 2015) (European Commission 2015).

Our study emphasizes on the development of a pesticide exposure pathway model by reducing the complexity of the system being studied in the model.

Table 4-2. A comparison of current Japan, Codex Alimentarius Commission and European Union MRLs (mg/kg).

Pesticide	Japan	CAC	EU
Azoxystrobin	10	-	0.1
Chlorfenapyr	40	-	50
Clothianidin	50	0.7	0.7
Etoxazole	10	15	15
Spiromesifen	30	-	40
Thiacloprid	30	-	10

The model focuses on projecting the fate and transport of pesticides in different media in the tea plantation area after pesticide application, according to the Japanese GAP. The model could be used to support decisions to decrease the pesticide residues in crude green tea in order to meet the MRLs set by CAC or the EU.

4.2.3 Data Preparations

We collect the required data from several online databases, textbooks, scientific papers, including unpublished documents that we obtained from our plantation visit survey that was conducted between April and October 2014. Our defined data for parameter inputs are described below.

- Because most of the soil surface in the plantation area is covered by tea plants, the fraction of the applied pesticide that flows into the leaves compartment is assumed to be higher than that flowing into the soil compartment. The tea leaves to soil fraction is set to have a mean value of 60% and a standard deviation of 10%. Thus, approximately 60% ± 10% of the total pesticide application will flow to the tea leaves compartment immediately after application and the remainder will move into the soil compartment.
- The depth of the soil used for estimating the pesticide concentration in bulk volume of the tea plantation area is determined from the length of the roots of tea plants. This depth can be more than 30 cm of soil; however, most of the feeder roots are located in the top few centimeters from the soil surface (Zeiss & Braber 2001). Thus, the depth of soil is considered to be only 0.3 m.
- Values for the initial conditions of the system that are difficult to obtain or for which data are not available (example: pesticide concentration in the soil and tea leaves compartments, area of new tea plants) are set to zero. This is also the

setup for modeling purposes (in the dynamic simulation, we must input the initial condition value).

All the parameter data used for simulating the model, including the Japanese GAP values for Clothianidin and Azoxystrobin, are listed in Table 4-3 and 4-4. There are some variable data inputs that are restricted by the given probability distribution, because some of the input data have a normal distribution (mean, standard deviation). Thus, the model output of this study does not only provide a single or deterministic value but also an uncertain or probabilistic value.

Table 4-3. Pesticide specific parameter data for the model simulation.

No.	Parameter	Value	Note/Data Source
1	Azoxystrobin GAP: -Dosage forms percent active ingredient dillution factor application rate	 20% $kg \cdot L^{-1}$ 2000 1000~4000 $L \cdot ha^{-1}$	(MAFF 2014); (Kyoto Tea Production Council 2013)
	-PHI (preharvest interval)	14 days	
2	Azoxystrobin properties data: -$t_{1/2\ soil}$ (Dissipation half-life in soil)	45 days	(DynamiCROP team 2015)
	-K_{OW} (Partition coeff. octanol/water)	316.228 $kg \cdot m^{-3}/kg \cdot m^{-3}$	
	-K_{OC} (Partition coeff. organic carbon/water)	0.423 $m^3 \cdot kg^{-1}$	
	-K_{AW} (Partition coeff. organic air/water)	2.7×10^{-12} $kg \cdot m^{-3}/kg \cdot m^{-3}$	
	-β_{subst} (Multiplicative substance correction factors)	Normal (-0.05, 0.06)	(Fantke et al. 2014b)
3	Clothianidin GAP: -Dosage forms percent active ingredient dillution factor application rate	 16% $kg \cdot L^{-1}$ 2000~4000 2000~4000 $L \cdot ha^{-1}$	(MAFF 2014) (Kyoto Tea Production Council 2013)
	-PHI	7 days	
4	Clothianidin Properties data: -$t_{1/2\ soil}$ (Dissipation half-life in soil)	550 days	(DynamiCROP team 2015)
	-K_{OW} (Partition coeff. octanol/water)	8.035 $kg \cdot m^{-3}/kg \cdot m^{-3}$	
	-K_{OC} (Partition coeff. organic carbon/water)	0.160 $m^3 \cdot kg^{-1}$	
	-K_{AW} (Partition coeff. organic air/water)	48.4×10^{-15} $kg \cdot m^{-3}/kg \cdot m^{-3}$	
	-$\beta_{Clothianidin}$ (Multiplicative substance correction factors for Clothianidin)	Normal (0.32, 0.13)	(Fantke et al. 2014b)
5	α (Intercept)	Normal (0.595, 0.04)	
6	Processing factor of green tea ($Pf_{green\ tea}$)	2.3	(FAO 2005)

Table 4-4. Environmental specific parameter data for the model simulation.

No.	**Parameter**	**Value**	**Note/Data Source**
1	Initial immature tea plant (2013)	2.01ha	(Shizuoka Prefecture 2014)
2	Initial Mature tea plant (2013)	180.99 ha	
3	Abandon rate	Normal (1.1%, 1.1%)/365 days	
4	Productive time	9855 days	
5	Transition time of seedling to immature	1460 days	(ITOEN 2015) (WGTA 2015a)
6	Transition time of immature to Mature	1095 days	
7	Tea leaves biomass	12000 $kg \cdot ha^{-1}$	(Leary et al. 2008)
8	Soil depth	0.3 m	(Zeiss & Braber 2001)
9	$Soil_{Pore}$ (Fraction of water-filled pores)	0.3 $m^3 \cdot m^{-3}$	(Baumgarten et al. 1998)
10	$Soil_{Porosity}$ (Porosity of soil)	0.5 $m^3 \cdot m^{-3}$	
11	D_{Soil} (Density of soil)	1300 $kg \cdot m^{-3}$	(Baumgarten et al. 1998)
12	OC (Organic carbon content of soil)	0.02 $kg \cdot kg^{-1}$	
13	Q (Transpiration stream)	10 $m^3 \cdot day^{-1}$/ha	
14	Leaves to soil fraction	Normal (60%, 10%)	Estimation
15	$\beta_{Tea\ plant}$ (Multiplicative tea plant correction factors -tea-)	Normal (-0.23, 0.04)	(Fantke et al. 2014b)
16	T_{ref} (Reference temperature)	293.16 K	
17	β_T (Multiplicative temperature correction factors)	Normal (0.01995, 0.003) Kelvin (K)	
18	T (Actual temperature; Shizuoka's monthly average temperature): -January	280.85 K	(Time-j.net 2015)
	-February	281.45 K	
	-March	284.45 K	
	-April	289.05 K	
	-May	292.95 K	
	-June	296.15 K	
	-July	299.85 K	
	-August	301.15 K	
	-September	298.25 K	
	-October	293.05 K	
	-November	288.05 K	
	-December	283.15 K	
19	Shizuoka's annual average temperature	290.65 K	

Note: Some data inputs for the model simulation use a normal distribution, for example the Abandon rate (table no.4) is Normal (1.1%, 1.1%)/365 days, it means that per year or 365 days, the value input is using a normal distribution with the mean and standard deviation values are 1.1% and 1,1%, respectively.

4.2.4 Simulation

In the real system, the growers apply pesticides in almost every month (KTIC, 2013), including in the dormant period that is in the end of October to the end of February (WGTA 2015a). Thus, the simulation of the pesticide fate and transport in the tea plantation after application is conducted as follows.

The pesticide is assumed to be applied once per month, at the beginning of each month, according to the area of mature tea plants. The amount of pesticide applied follows the Japanese GAP for the dosage treatment (listed in Table 4-3, items 1 and 3). For the baseline simulation, we follow common dosage forms, which are percent active ingredient (a.i): 20% kg/L, dilution factor (d.f): 2000 and application rate (a.r): 2000 L/ha or 0.2 kg a.i/ha for Azoxystrobin (Food Safety Commission 2013). For Clothianidin is a.i: 16% kg/L, d.f: 2000 and a.r: 4000 L/ha or 0.32 kg a.i/ha (Food Safety Commission 2014). Simulations under a given set of the circumstances are run for 1 year with a time step of 1 day for the base year 2013.

To deal with all uncertainty sources in this model, such as inadequate model structures (simplification of the real system) and variable data input, a Monte Carlo (MC) simulation is run simultaneously. Thus, the model output shown in this study is the mean value of the uncertain values that are estimated using 500 random samples applied to entire model.

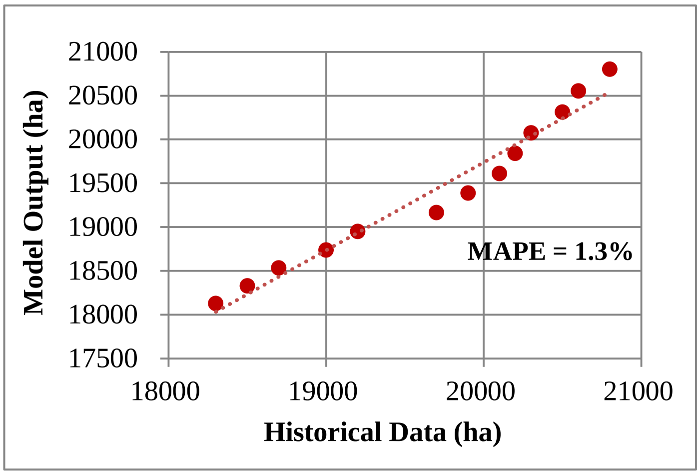
4.3 Result and Discussion

4.3.1 Model Validation

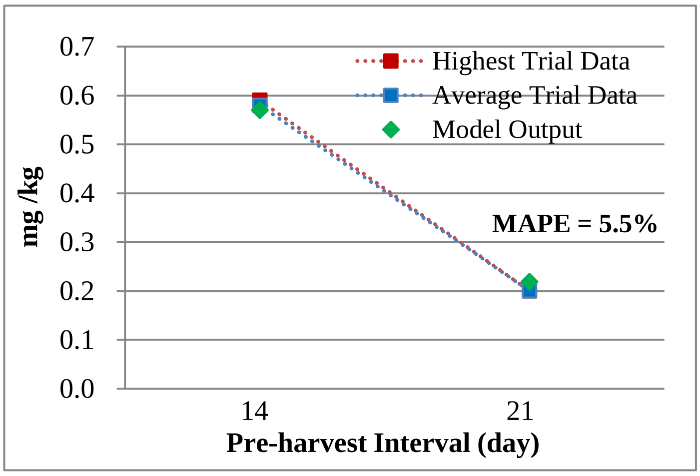
The model is validated on the basis of the real system data. Reproduction data testing is conducted to build confidence that the model is acceptable for its intended use.

For the tea plant developmental stages sub-model, the testing is conducted by simulating the model for the past, then comparing the model projection data with historical data. The total area of tea plantations in Shizuoka Prefecture for the period 2001–2013 (Shizuoka Prefecture 2014) are used to verify how well the sub-model is able to reproduce real patterns of the tea plantation area in Shizuoka. For the pesticide fate and transport sub-model, data on pesticide residues in crude green tea, derived from highest and average field trial data with PHI of 7, 14 and 21 days (Food Safety Commission 2013, 2014) are used to verify how the model is able to project the pesticide fate and transport in the tea plantation area. Because it is not clear what month the field trial data were obtained in, in this test we used the annual average temperature data of Shizuoka Prefecture.

a. Model output and historical data for the tea plantation area in Shizuoka Prefecture for the period 2001–2013.



b. Model output and field trial data for Azoxystrobin residue in crude green tea.



c. Model output and field trial data for Clothianidin residue in crude green tea.

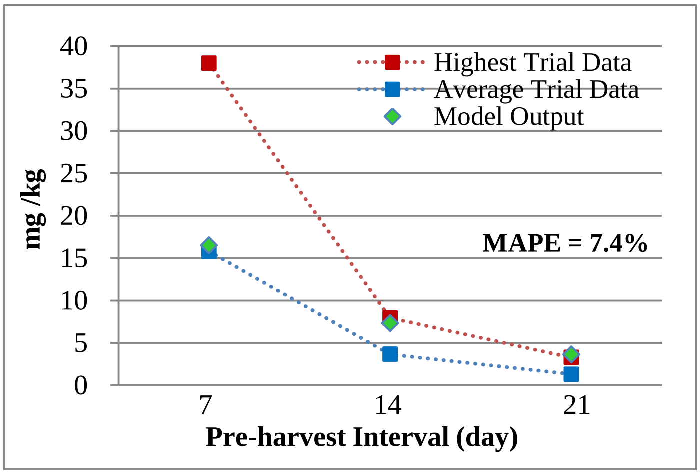


Figure 4-2. Model validation result.

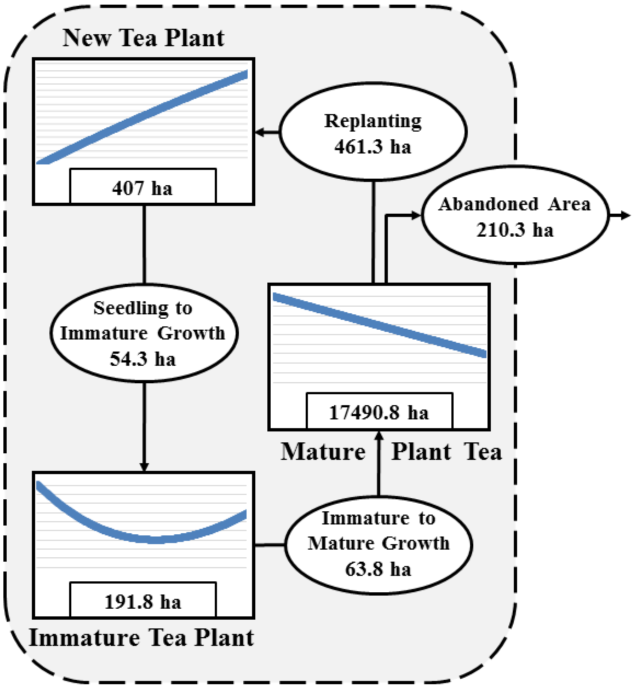
Figure 4-2.a, b, and c show comparisons of model output versus real system data. The mean absolute percent error (MAPE) of the total tea plantation area is 1.3%.The MAPE values of pesticide residue in crude green tea (obtained from the closest point of the trial data) are 7.4% and 5.5% for Clothianidin and Azoxystrobin, respectively. This indicates that the model is able to reproduce the structure of the real system, because the model output corresponds to the real system data. Thus, this model is useful and might have good predictive power.

4.3.2 Mass Balance

The simulation results of mass balance of the two sub-models are presented in Figure 4-3. The graphs inside each compartment depict the dynamic change patterns of the stocks. The immature tea plant compartment shows a decline at first and then an increase: this occurs because the initial data input for the area of new tea plant is set at zero. Therefore, there are no seedlings that became immature plants at the beginning of the simulation. The compartments of new and mature tea plants increase and decrease through time, respectively. The succession from immature to mature tea plant areas increases at 63.8 ha/year. The mature tea plant compartment declines due to tea plants that have reached their maximum lifetime and should be removed, with a value of approximately 671.7 ha/year. The aging tea plants that are not replanted (i.e., the abandoned area) is approximately 210.3 ha/year. As a result of removal and replanting, the new tea plant compartment increases by 461.3 ha/year, and the succession from new to immature tea plant areas rises at a rate of 54.3 ha/year. Overall, the total area of tea plantations in Shizuoka declines over time, and this trend is likely to continue for the future. The consequence of this trend is that the amount of pesticides used should decline, because pesticide use is primarily dependent on the area of tea plantations.

In this simulation, total pesticide use for the Shizuoka tea plantations are about 42764.2 and 68422.7 kg a.i/year for Azoxystrobin and Clothianidin, respectively. The amounts of Azoxystrobin that move into the soil and tea leaves compartments per year are approximately 17155.9 and 25608.3 kg, respectively. For Clothianidin the values are around 27449.5 and 40973.3 kg, respectively.

a. Sub-model of tea plant developmental stages



b. Pesticide fate and transport sub-model.

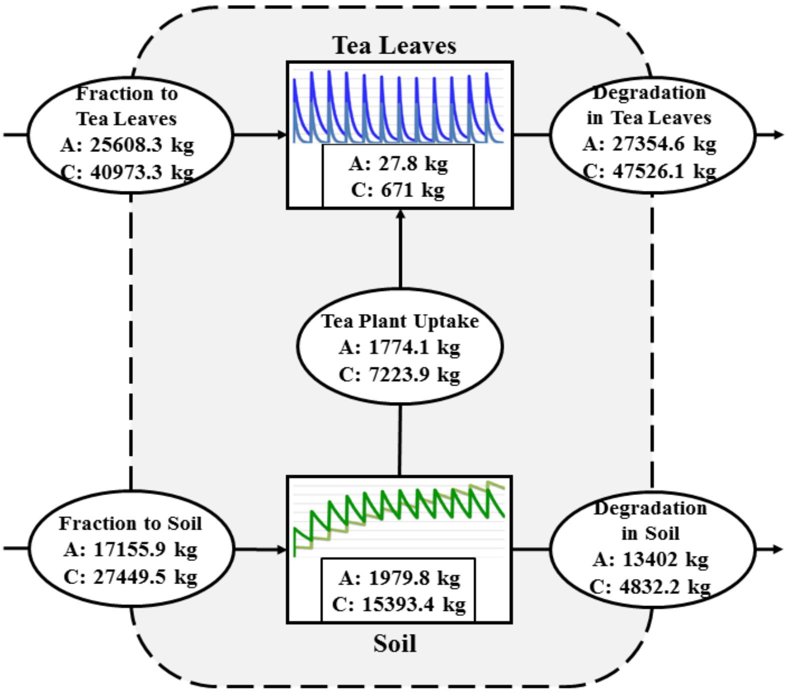


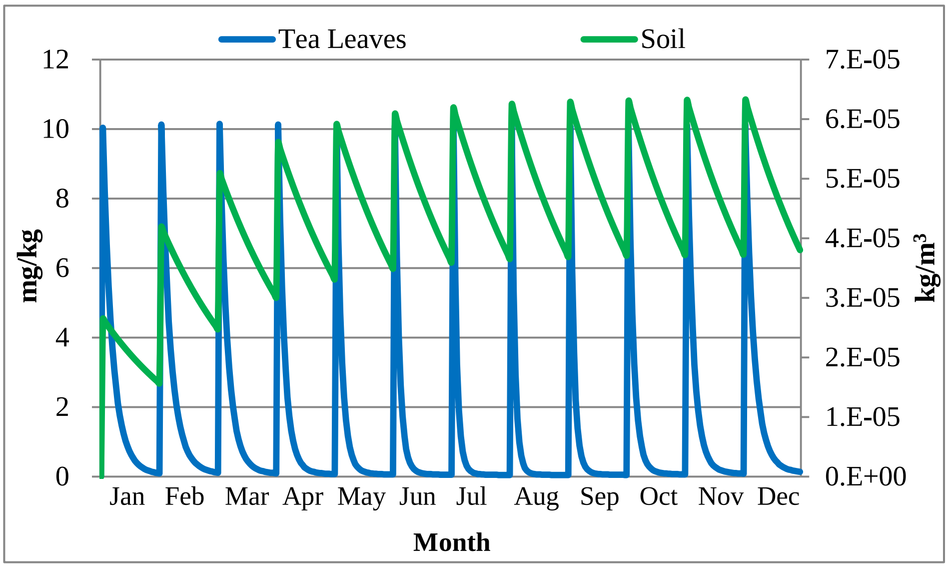
Figure 4-3. Simulation results for mass balance for one year (2013-2014).
For the tea plant developmental stages sub-model, flows and compartments are in ha. For the pesticide fate and transport sub-model, flows and compartments are in kg. A denotes Azoxystrobin, and C denotes Clothianidin. The graphs in each compartment show the dynamic behavioral pattern of the corresponding compartment. Please see appendix for detailed quantitative information per month in all compartments and flows.

The dynamic changes in the pesticide mass in the soil and tea leaves compartments demonstrate that there are some pesticides that are not degraded from the previous application. Thus, accumulation of pesticides occurs in both compartments in a stair-stepped increase pattern when the pesticide is used repeatedly in the plantation, although simultaneous degradation also takes place. The degradation of Azoxystrobin in the soil and tea leaves compartments are around 13402 and 27354.6 kg/year, respectively. The values for Clothianidin are approximately 4832.2 and 47526.1 kg/year, respectively.

Pesticide accumulation in the soil compartment increases steadily in line with the frequency of pesticide use. The soil compartment is the main sink for the pesticide, accumulating average amounts of 1979.8 and 15393.4 kg/year of Azoxystrobin and Clothianidin, respectively. As a result, pesticide uptake rate by tea plants will also increase over time. In this simulation, the uptake rate by tea plants at the beginning and end of the simulations increases nearly 2.4 and 7.5 times for Azoxystrobin and Clothianidin, respectively. The amounts of pesticides in the soil compartment that are taken up by tea plants and subsequently deposited in the tea leaves compartment are approximately 1774.1 and 7223.9 kg/year for Azoxystrobin and Clothianidin, respectively. Hence, degradation of pesticides in the tea leaves compartment exceeds the fraction of the applied pesticide that flows into the compartment. Furthermore, Azoxystrobin more quickly reaches steady-state conditions in the soil compartment after several applications compared to Clothianidin, because the dissipation half-life of Azoxystrobin in soil (45 days) is shorter than that of Clothianidin (550 days).

In contrast to the soil compartment, the increase of the pesticide accumulation in the tea leaves compartment is not steady, but fluctuates, with average values of 27.8 and 671 kg/year for Azoxystrobin and Clothianidin, respectively. The fluctuations are due to the dissipation rates that vary from month to month and are largely affected by environmental temperature. High temperature increases the dissipation rate; low temperature reduces the rate. The dissipation rates of Azoxystrobin are in the range 1.5–3.9 days; the values are 3.8–9.5 days for Clothianidin. The highest dissipation rate is observed in August and the lowest in January, because the maximum and minimum environmental temperatures in Shizuoka occur during these months. Figure 4 shows changes in pesticide concentration in the soil (kg/m^3) and tea leaves (mg/kg). The simulation results show that, although fresh tea leaves are picked at the end of each month (PHI approximately 30 days), and then processed into crude green tea, the residue level for both pesticides is still higher than the MRLs set by CAC and the EU.

a. Azozystrobin



b. Clothianidin.

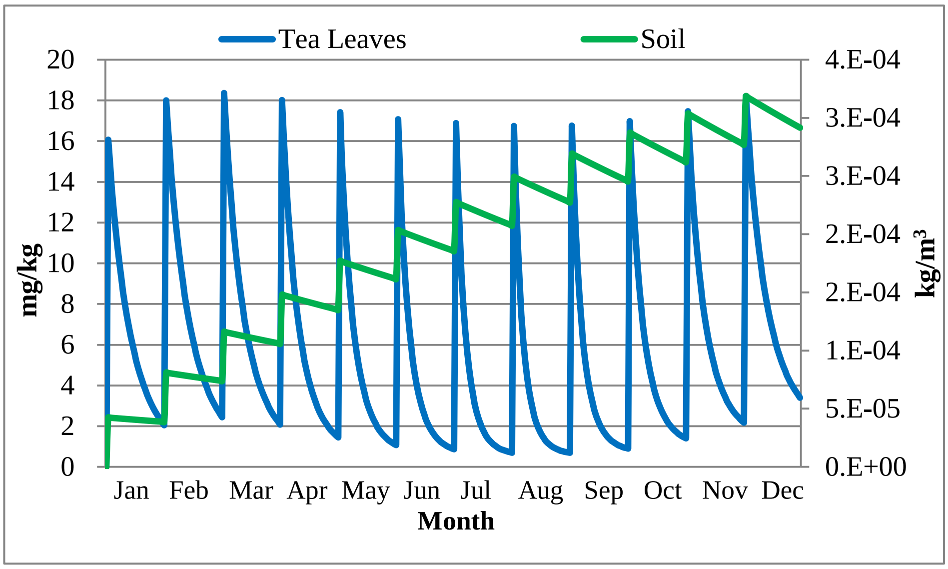


Figure 4-4. Changes in the pesticide concentrations in soil and tea leaves with monthly applications of Azoxystrobin and Clothianidin.

This finding demonstrates that, if Japan wishes to meet the CAC and EU standards, the new PHI required would be markedly different from the current value.

4.3.3 Preharvest Interval Estimation

Interrupted simulations are conducted to estimate and obtain an overview of the PHI of the pesticides by ensuring that the pesticide residue in crude green tea is

less than the MRLs set by CAC and EU. The purpose of these simulations is to determine the usage pattern of pesticides that will probably lead to the highest residue and its effects on the PHI. In the following simulation, the pesticide is applied on the first day of every month using the maximum dosage treatment of the Japanese GAP (Table 4-3, items 1 and 3). The maximum dosage forms for Azoxystrobin and Clothianidin are 0.4 kg a.i/ha (a.i: 20% kg/L, d.f: 2000, a.r: 4000 L/ha) and 0.32 kg a.i/ha (a.i: 16% kg/L, d.f: 2000, a.r: 4000 L/ha), respectively.
It is noted that this following simulation is still under initial condition which set to zero. Actually, the estimated result will depend on the initial condition in the real system. Thus, to study the effect of initial condition value, we will discuss it in the section 3.5.

The simulation results are summarized in Table 4-5. For instance, if Azoxystrobin is applied on May 1, safe harvesting should be conducted at least 38 days later, around June 7, with an estimation of the pesticide concentration in tea leaves of 0.041 (±0.015) mg/kg. After the freshly picked tea leaves have been processed, the pesticide residue in crude green tea is estimated to be 0.095 (±0.034) mg/kg. The PHI varies according to the timing of pesticide application despite using the same dosage forms. Therefore, determination of PHI should also consider the timing of pesticide application in addition to the dosage treatment. Furthermore, the PHI should not be applied as a fixed time. Consequently, if PHI must be fixed, the longest possible PHI should be used to ensure safety.

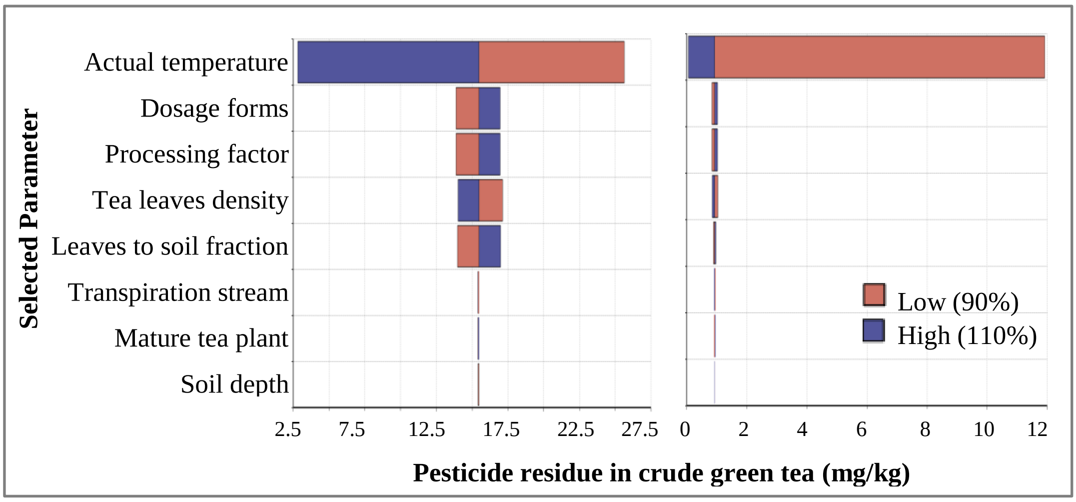
Table 4-5. Overview of the preharvest interval of the pesticides.

Month	Azoxystrobin				Clothianidin			
	PHI (day)	**Harvest date**	**Concentration in tea leaves (mg/kg)**	**Residu in crude green tea (mg/kg)**	**PHI (day)**	**Harverst date**	**Concentration in tea leaves (mg/kg)**	**Residu in crude green tea (mg/kg)**
January	71	March 12	0.042(±0.016)	0.096(±0.037)	77	March 18	0.299(±0.236)	0.689(±0.542)
February	64	April 5	0.041(±0.016)	0.094(±0.036)	68	April 9	0.29(±0.242)	0.667(±0.558)
March	57	April 25	0.041(±0.015)	0.095(±0.034)	57	April 26	0.292(±0.249)	0.672(±0.572)
April	45	May 15	0.042(±0.015)	0.097(±0.035)	46	May 16	0.282(±0.254)	0.651(±0.585)
May	38	June 7	0.041(±0.015)	0.095(±0.034)	39	June 8	0.273(±0.255)	0.627(±0.586)
June	32	July 2	0.041(±0.015)	0.093(±0.035)	33	July 3	0.275(±0.27)	0.632(±0.62)
July	26	July 26	0.04(±0.015)	0.097(±0.035)	28	July 28	0.316(±0.323)	0.609(±0.617)
August	23	August 23	0.043(±0.016)	0.097(±0.036)	26	August 26	0.265(±0.276)	0.611(±0.635)
September	44	October 14	0.042(±0.015)	0.097(±0.034)	30	September 30	0.279(±0.275)	0.641(±0.633)
October	58	November 27	0.043(±0.015)	0.098(±0.035)	45	November 14	0.292(±0.237)	0.671(±0.546)
November	79	January 18	0.042(±0.016)	0.097(±0.036)	68	January 7	0.297(±0.205)	0.682(±0.484)
December	78	February 16	0.042(±0.016)	0.097(±0.037)	81	February 19	0.299(±0.214)	0.688(±0.493)

4.3.4 Uncertainty Analysis

Of the many sources of uncertainty in the model, this study considers only the uncertainty that comes from the parameter inputs. Sensitivity analysis is conducted on the parameters that are considered to have most influence on the behavior of the overall model. The selected parameters are investigated according to the output variable of pesticide residue in crude green tea. The selected parameters are varied by the same amount to low (90%) and high (110%) levels of their nominal values.

a. Azoxystrobin



b. Clothianidin

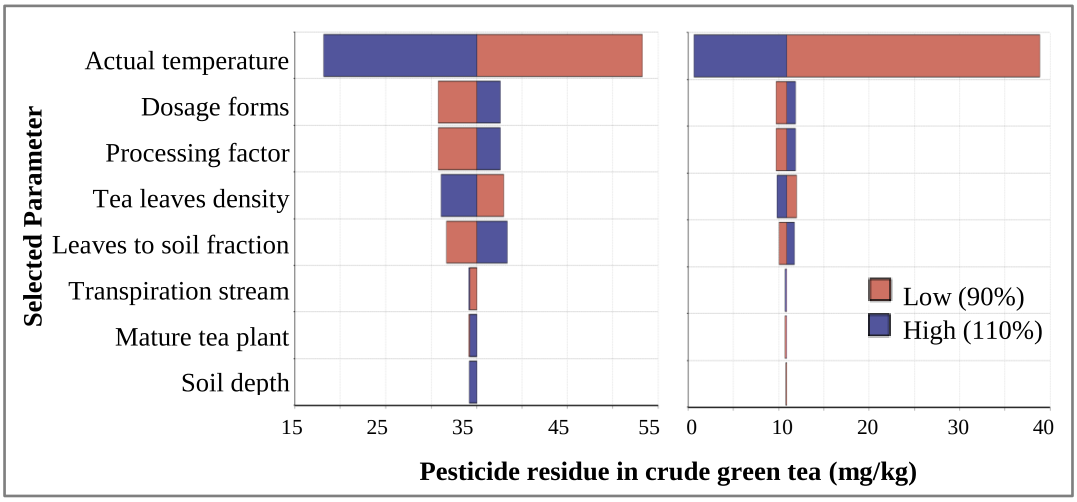


Figure 4-5. Sensitivity analysis for the model at the beginning and end of the simulation per month after application of pesticides.

The sensitivity analysis results are illustrated in a tornado diagram (Figure 4-5) that depicts the influence rank order of the selected parameters with respect to pesticide residues in crude green tea. The results change over time for the two pesticides, but some general patterns are discernible. After application of pesticide, the influence of the parameters continues to decline gradually over time with the exception of actual temperature. Variations in the actual temperature cause more than 70% (for Azoxystrobin) and 50% (for Clothianidin) of the changes in the pesticide residue in crude green tea. The dosage forms, processing factor, and tea leaves density are the second most influential parameters, causing around 10% of the changes for both pesticides. The leaves to soil fraction is third-most influential, responsible for 4%–10% of the change for Azoxystrobin and 7%–10% for Clothianidin. The parameters of transpiration stream, mature tea plant, and soil depth (which cause less than 3% of changes for both pesticides), are virtually insensitive to changes in the pesticide residue in crude green tea. Thus, actual temperature is the most influential parameter in terms of its contribution to the uncertainty in the pesticide residue in crude green tea. This result is in accordance with the simulation results discussed in the previous section, since timing of the pesticide application that is considered in this study is influenced by the actual temperature, which is a tea plantation area-specific factor.

The parameters that have a significant effect on the selected output variable may be used for decision analysis. From the outcome of this sensitivity analysis, actual temperature and dosage forms are two factors that decision-makers need to consider at plantation management level in terms of pesticide application.

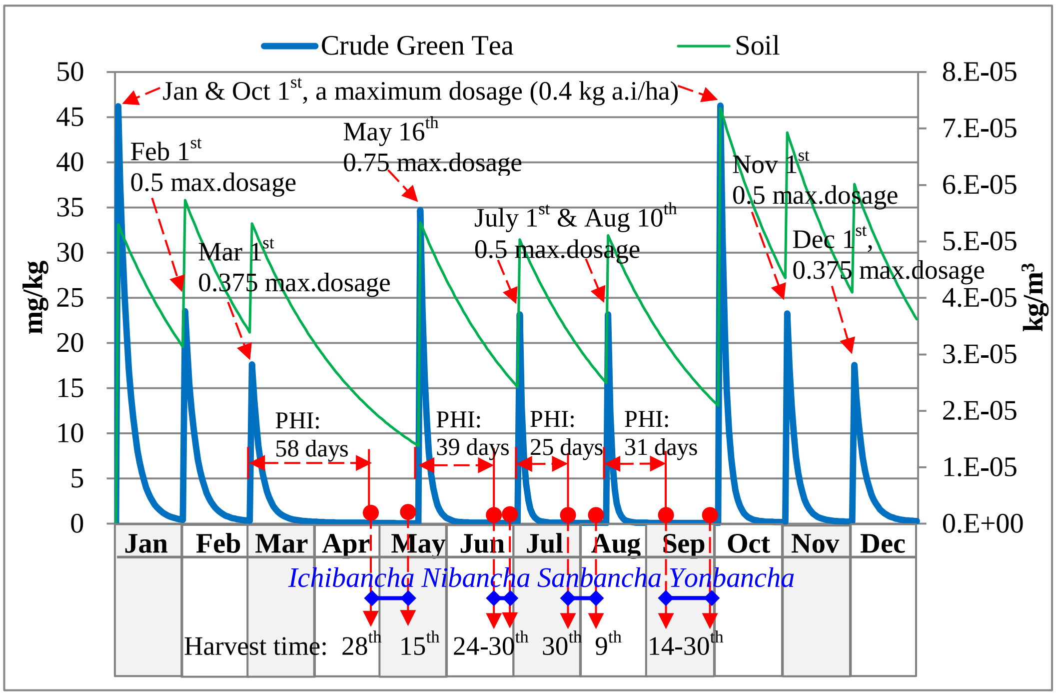
4.3.5 Model Use for GAP Recommendations

The following is an example for use of the model to support decisions for decreasing the pesticide residue level in crude green tea in order to meet the default MRL values set by CAC and the EU. We focus on the fresh tea leaves that are harvested between April and October, which are called Ichibancha, Nibancha, Sanbancha, and Yonbancha. Under this simulation, a combination of the timing of application (i.e., temperature conditions) and the dosage treatment are adjusted to the harvest time of the fresh tea leaves. The harvest times are set at specific times because these are considered to be the best opportunities to obtain high-quality fresh tea leaves. Icibancha is harvested in late April to mid May. Nibancha, Sanbancha, and Yonbancha are harvested in late June, late July to early August, and mid September, respectively (WGTA 2015a).

Figure 4-6 illustrates the proposed GAP for Azoxystrobin and Clothianidin. For Ichibancha, the last application of pesticide (0.15 kg a.i /ha for Azoxystrobin and 0.08 kg a.i/ha for Clothianidin) must be conducted at least 58 days before the harvest date. When pesticide is applied at the beginning of March, the harvest should be started on April 28 and carry on until May 15. For Nibancha, pesticide (0.3 kg a.i /ha for Azoxystrobin and 0.213 kg a.i/ha for Clothianidin) should be applied immediately after the harvest of Ichibancha has finished. If pesticide is applied on May 16, the harvest can be conducted between 39 and 41 days later, on June 10 for Azoxystrobin and June 26 for Clothianidin, and may continue till the end of June. If pesticides are applied (0.2 kg a.i /ha for Azoxystrobin and 0.6 kg a.i/ha for Clothianidin) immediately after finishing the harvest of Nibancha on July 1, the Sanbancha harvest can be started in the same month, on July 26 (Azoxystrobin) and 30 (Clothianidin), and last until August 9. For Yonbancha, the same dosage as for Sanbancha could be applied on August 10 and the harvest could begin 31 and 35 days later, i.e., on September 10 and 14 for Azoxystrobin and Clothianidin, respectively. In the dormant period, the same dosage pattern as for January to March could be applied for October to December.

The same simulation is also conducted to study the effect of initial condition value. Under this simulation, the model is run from January 2003 to December 2012. The pesticide mass in the soil and tea leaves compartments at end of December 2012 then are used as initial condition (in January first 2013). From the simulation (Figure 4-7 and 4-8), initial condition values for Azoxystrobin in soil and tea leaves compartments are 1796 and 25.95 kg, respectively. For Clothianidin in soil and tea leaves compartments are 19982 and 790.87 kg, respectively.

a. Azozystrobin.



b. Clothianidin.

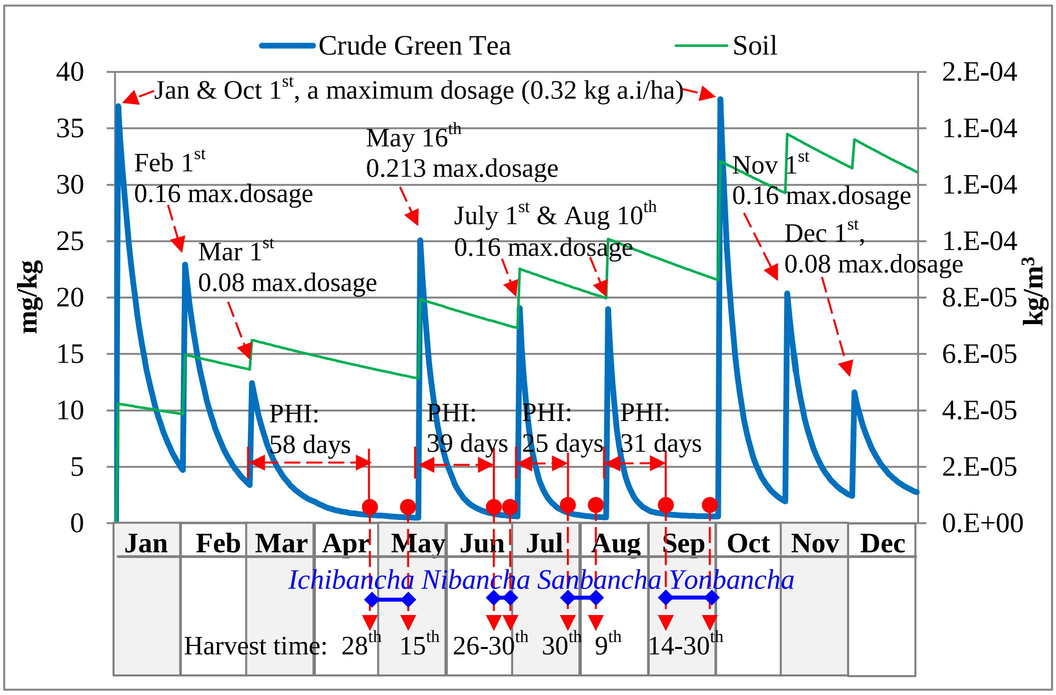
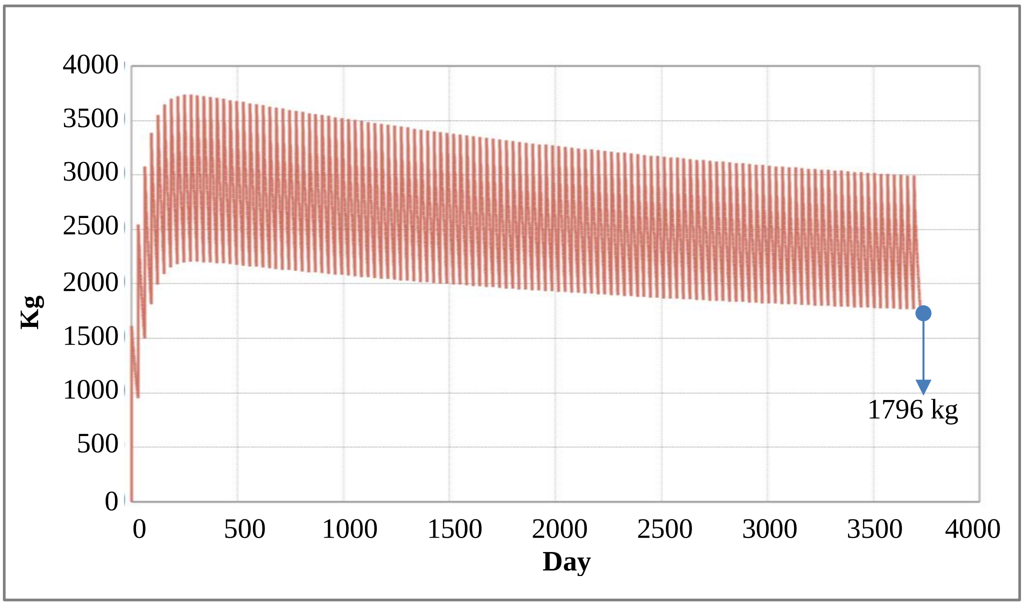


Figure 4-6. The proposed GAP to meet the MRLs set by CAC and the EU.

The graph depicts the pesticide residue in crude green tea that is after freshly picked tea leaves are processed. According to the Japan's GAP, maximum dosage for Azoxystrobin and Clothianidin are 0.4 kg a.i/ha (a.i: 20% kg/L, d.f: 2000 and a.r: 4000 L/ha) and 0.32 kg a.i/ha (a.i: 16% kg/L, d.f: 2000 and a.r: 4000 L/ha), respectively. Thus, 0.75, 0.5, 0.25 0.375 of the maximum dosage is also formulated within the range of the Japan's GAP, for example: 0.25 of the maximum dosage for Clothianidin is the dosage forms of a.i: 16% kg/L, d.f: 4000, a.p: 2000 L/ha.

a. Azoxystrobin dynamics in soil compartment.



b. Azoxystrobin dynamics in tea leaves compartment.

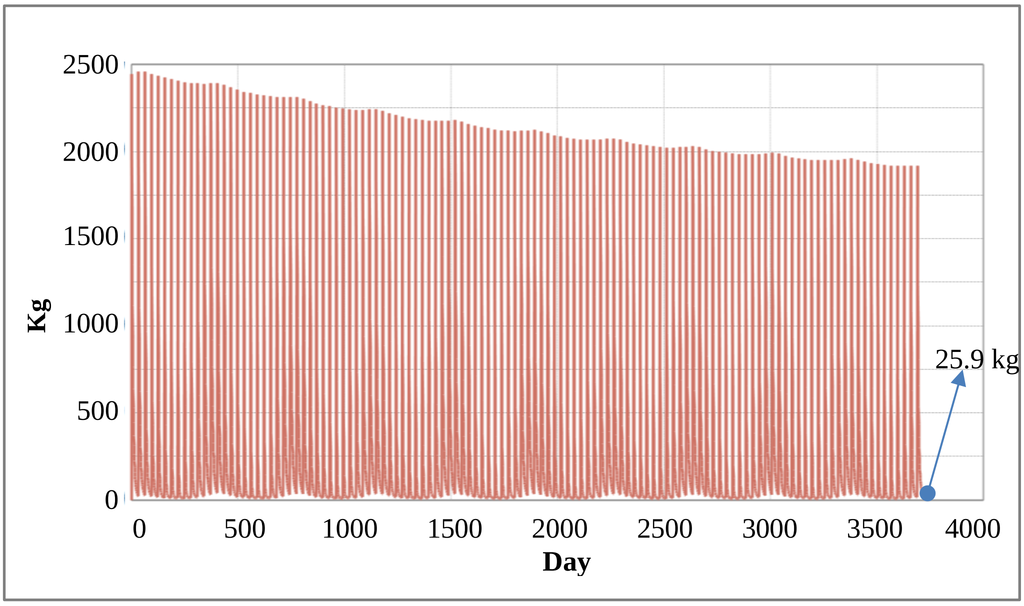
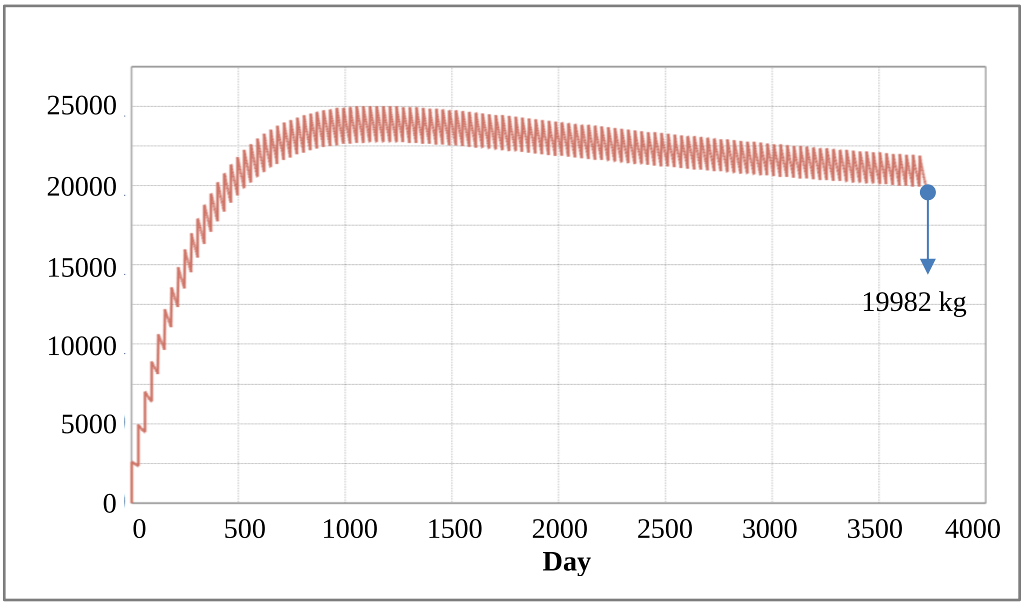


Figure 4-7. The simulation result for the time period January 2003 to December 2012 in order to get initial condition value in soil and tea leaves compartments for Azoxystrobin.

a. Clothianidin dynamics in soil compartment.



b. Clothianidin dynamics in soil compartment.

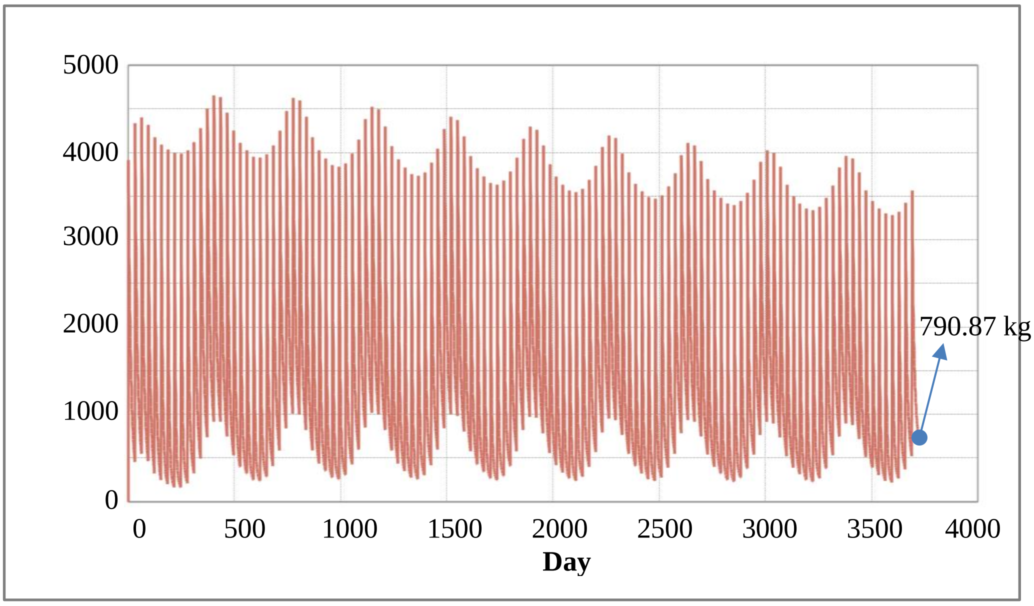
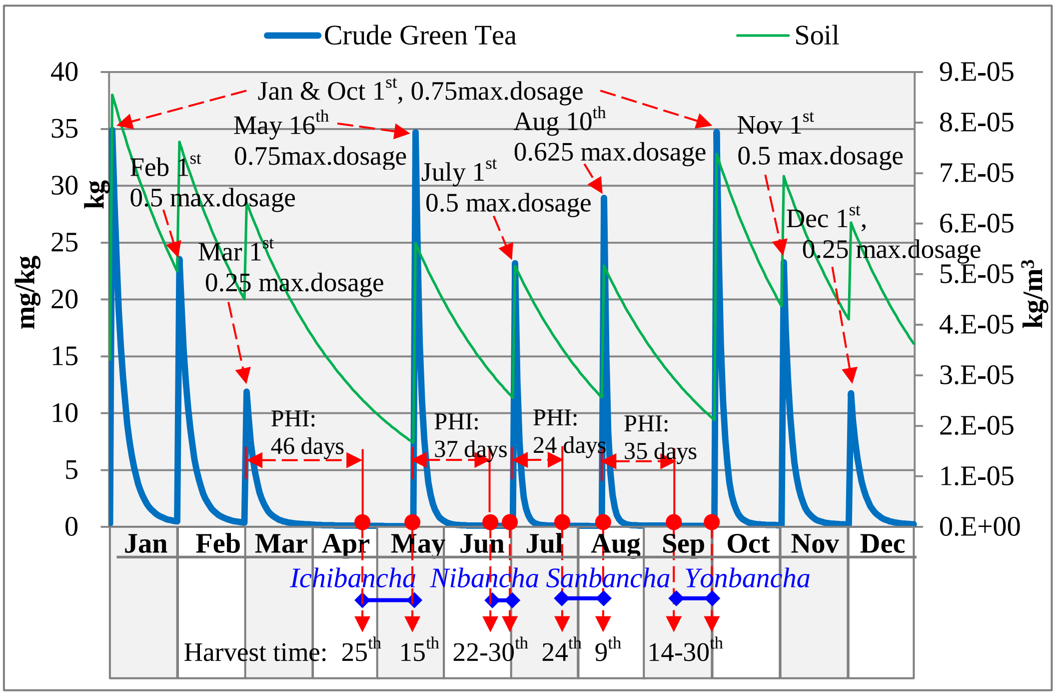


Figure 4-8. The simulation result for the time period January 2003 to December 2012 in order to get initial condition value in soil and tea leaves compartments for Clothianidin.

a. Azozystrobin.



b. Clothianidin.

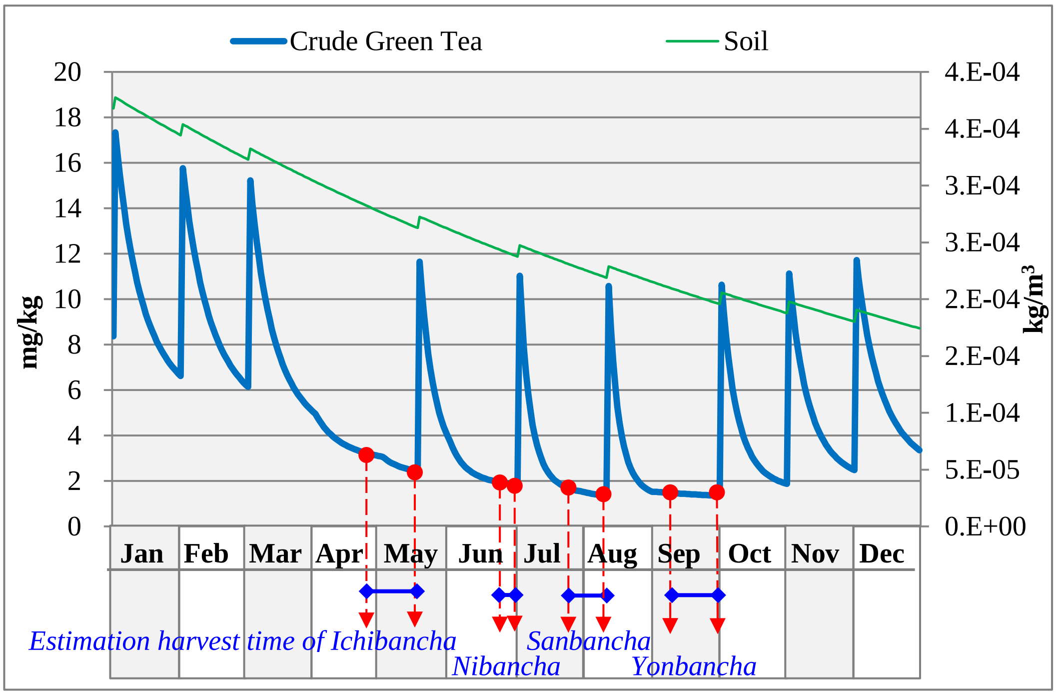


Figure 4-9. The proposed GAP to meet the MRLs set by CAC and the EU with the initial condition value.

For Clothianidin, although the pesticide is applied by following the patterns in Figure 6.b using the minimum dosage treatment of 0.08 kg a.i /ha or 0.25 of maximum dosage (a.i: 16% kg/L, d.f: 4000 and a.r: 2000 L/ha), the pesticide residue level in crude green tea will remain higher than the default MRLvalues set by CAC and the EU.

The proposed GAP for Azoxystrobin has similar results as shown in Fig.6.a, but it has different dosage treatment and harvest time (Figure 4-9). For Clothianidin, although the pesticide is applied by following the patterns in Fig.6.b using the minimum dosage treatment (0.25 maximum dosage = 0.08 kg a.i /ha), the pesticide residue level in crude green tea will remain higher than the default MRL values set by CAC and the EU (Figure 4-10).

The way in which we manipulated the simulation above for alternative GAP could also be implemented in the real systems of tea plantations. The main findings from this simulation are discussed below.

Although the pesticide concentration in soil will keep increasing in line with the frequency of pesticide use, adjustments in the timing of pesticide applications and formulation of the dosage treatments (still within the range of the current GAP) with specific provision for harvest times of fresh tea leaves are essential for controlling residue levels in green tea. It should be noted that the repeated use of pesticide that has long dissipation half-life, such Clothianidin, should be avoided. Furthermore, tea growers use various pesticides for controlling pests and diseases (certain pesticides are used for certain pests/diseases); thus, sufficient field trial data are indispensable to determine the time interval between the last application of pesticide and tea leaf harvesting. Thus, it is suggested that field trials on the timing of pesticide application should be conducted in a real system for all pesticides that are commonly used.

4.4 Conclusion

Green tea is one of the agricultural commodities of Japan for which there exists a barrier for entry to the global market in that the default MRL values for some pesticides are much higher than the values of CAC or the EU. This study presents the development of a pesticide exposure pathway model for the analysis of two pesticides using Shizuoka tea plantations as a case study. The aim of carrying out this simulation was to be able to reduce residue levels in green tea and propose an alternative GAP. Our main conclusions are summarized below.

The model demonstrated that the dissipation rates of pesticides in tea leaves that affect the rate of pesticide degradation, vary according to the timing of pesticide application, which in turn is influenced by factors specific to the plantation area. Accordingly, the PHI will also vary despite using the same dosage forms during pesticide application. As PHI is one of the crucial provisions in the GAP that will largely affect pesticide residues in green tea, the implementation of a fixed PHI time might not be appropriate.

The main recommendation for GAP from this study is that the incorporation of factors specific to individual plantations, such as temperature, in the GAP guidelines is essential in order to maintain pesticide residues under the desired levels. Furthermore, to produce good-quality, safe green tea, the GAP should provide detailed and precise guidelines on the timing of pesticide applications and formulation of dosage treatments considering specific provisions for the harvest times of fresh tea leaves.

One goal of developing this model was to enhance the understanding of the fate and transport of pesticides in tea plantation areas associated with the application of GAP. Two pesticides have been analyzed by the model for a given set of circumstances. From the model validation results, our model can successfully represent the structure of the real system. Thus, the model should be applicable to other pesticides and sites; however, some adjustments for different cases may be necessary.

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CHAPTER 5

ENVIRONMENTAL BURDEN OF INDONESIAN PALM OIL AND JAPANESE GREEN TEA

5.1 Introduction

The origin of palm oil (*Elaeis guineensis*) is believed from Africa. The palm oil gives the highest yields per hectare compares with other oil crops, that is approximately 4.2 Mg per ha per year (Tan et al. 2009). It led to a rapidly expanding the industry which now based in the tropical areas of Asia, Africa and America. Nowadays, the most productive countries of the palm oil industry recently are in Indonesia and Malaysia which provide most of the palm oil in the international trade (Corley & Tinker 2003) (USDA-FAS 2015).

The origin place of tea (*Camellia sinensis*) was estimated to be around Chinese Yunnan district, but it is not confirmed yet. Since, one type variety of Camellia sinensis was discovered in India at 1835 and thereafter also in Thailand and Burma. Camellia sinensis has two varieties of sinensis and assamica (WGTA 2015b).

5.2 Historical Trends

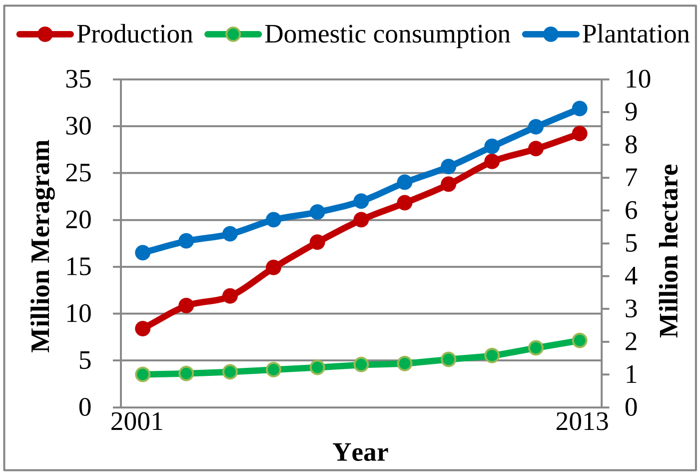
The trends of Indonesian palm oil (IPO) (Figure 5-1.a) have been increasing during 2001-2013 period for production, plantation, or domestic consumption (USDA-FAS 2006) (USDA-FAS 2009) (MOARI 2014) (USDA-FAS 2015) (BPS-Indonesia 2011) (BPS-Indonesia 2015). There are more plantation areas established during the period and more production to meet the growing demand. The figure describes the consistently increasing situation.

In the other hand, the different situation is indicated in the Figure 5-1.b (Japanese Association of Tea Production 2015) for the Japanese green tea. The production and demand consumption of Japanese green tea (JGT) is fluctuating. While the tea plantation areas tend to decrease over the time.

5.3 Environmental Load Overview

Environmental load which is defined in this study are the amount of input-output flow of raw materials, energy, air and liquid emissions, substances,

a. Indonesian palm oil.



b. Japanese green tea.

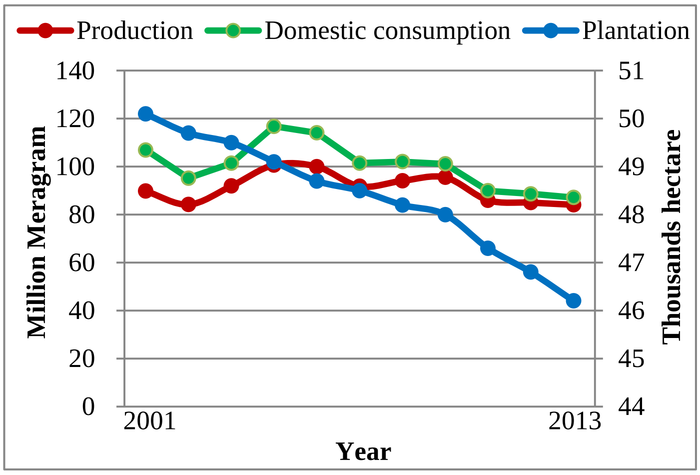


Figure 5-1. Historical trends of plantation, production and domestic consumption of both agriculture product.

solid and liquid wastes that have potential or actual environmental impacts. The following describes briefly a comparative environmental load between palm oil and green tea that limited to the plantation production supply chains.

The land use change for IPO keeps on increasing over time. The land conversion for palm oil plantations is inevitable in order to increase the production to meet the global demand. As a result, about 99% of GHG emissions resulted from the IPO industrial sector is from its LUC production supply chain (as has been discussed in Chapter 3). In contrast to the IPO, there is no land use change for JGT. The trend of tea plantation is decreasing over time.

a. Air stirring method (antifrost fan), prevent frosting by blowing stirring warm air to the tea field

b. Rail for tracking plucking machine

Figure 5-2. Photos from our visit survey at Shizuoka in April 2014.
The photos depict that much more energy may be needed in the tea plantation compare to palm oil.

Although the tea plantation areas are declining over time but the amount of green tea production does not decline. This is an interesting phenomenon and needs to be studied (as an input for IPO). How still be able to meet demand while the tea plantation area continues to decline.

The tea leaves are practically harvested using plucking machine. In addition, the tea plantation also requires energy for the air-frost fan for the frost prevention. While, the fresh fruit bunches (FFB) of palm oil are harvested manually using hand-held tools (Pleanjai et al. 2007)(Soraya et al. 2014). It indicates that the use of energy in the palm oil plantation may lower than tea. Furthermore, the use of energy in the palm oil production supply chains may come either from fossil fuel-based or waste utilization fuel-based. Thus, the environmental load of palm oil plantation in energy can be reduced by utilizing its waste generations (i.e., biomass).

Most plantation production supply chain of palm oil is located in South East Asia, which classified as the tropical region. In such condition, there is no need more water consumption because the rain in the region already can meet the water required for the growth and productivity of oil palm crops on the plantation (Pleanjai et al. 2007)(Pasaribu et al. 2012)(Lubis et al. 2014).

Pruning and felling activities are main source of biomass waste generation in the plantation production supply chain for both palm oil and tea. However, considering their anatomy, it is obvious that palm oil generates much higher biomass waste than green tea.

5.4 Key Environmental Issue in the Global Market

Both palm oil and green tea plantations have contributed to some environmental problems. In local context, palm oil requires more land for its plantation areas as a result of global demand. The forest conversion has brought consequences such as the escalation of GHG emissions. The impact of the increase of GHG emissions is not only to local area but also to the global level. It becomes one of the causes of climate change. Hence, the issue of forest conversion related to GHG emissions has served as the critical one. As the result, IPO cannot be exported to European countries because of the issue (as trade barrier) (Dharmawan & Sarianti 2015), which is same as with JGT.

The land use for green tea plantation is not huge problem as palm oil plantation because the data show that the plantation area for green tea is declining. The critical issue for green tea is more related to the pesticide use while for palm oil is rarely to discuss. A concern for human health has urged the raising awareness of food safety, including to the exposure of pesticide. Greenpeace (2012) has reported that some of the sample of tea product in China contained the level of pesticide residue which can endanger human health. The concern on pesticide use in green tea has arisen particularly because the pesticides directly go to the tea leaves which are the consumption part of tea production. Since it is not possible to make the food production such as green tea is free from pesticide, the maximum residue limit (MRL) of any pesticide in food commodity has been made.

5.4.1 Indonesian Palm Oil Associated With Human Health Evaluation Using DALY

For IPO, this study uses Disability adjusted life year (DALY) as end point indicator for the human health. DALY was introduced in 1993 as a measurement unit to quantify the burden of disease and injury of human population. DALY measures the gap between the actual health status of population and some references or the "ideal" status. One DALY is one lost year of healthy life (Murray, 1996). DALY is widely used as a tool to compare the global burden of disease. DALY is calculated with the basic formula as follows: DALY = YLL + YLD. Where YLL is years of life lost due to mortality and YLD is years lost due to disability. In the context of environmental, DALY is developed as end-point measurement for health risk due to environmental factors.

Palm oil industry has indicated their contribution in GHG emission. This emission has a negative impact to human health through the climate change. The situation has brought consequences as a health risk to the people. The magnitude of the effect to human health can be measured by using DALY. In this calculation, we refer to the study of De Schryver et al. (2009). The total DALY resulted from the GHG emissions of LUC and energy use in the production supply chains of palm oil industry in Indonesia is 6418310 DALYs (Table 5-1).

5.4.2 Japanese Green Tea Associated With Human Health

Green tea is one of popular beverages in the world. Nowadays, people believe that consuming green tea can bring health benefits. Some studies have been done related to green tea in its role to reduce the risk of non-communicable diseases such as coronary heart disease (Sano et al. 2004), diabetes (Iso et al. 2006), and prostate cancer (Kurahashi et al. 2008). Those evidences have encouraged people to consume more green tea in order to make them healthy. However, green tea may also pose health hazard because of the pesticide residue still remain in its final product. The green tea consumption also become an important route for human to be exposed to pesticide residue (Jaggi et al. 2001). The use of pesticide in green tea plantation is inevitable since pesticides have played an important role in increasing agricultural productivity.

Since the residue of pesticide in tea leaves may endanger human health, there is a reference for the maximum residue limits (MRL) which considered for the global trade of green tea. It is importantly noted that MRLs for pesticide residue are not measuring the level of toxicity. The significant level of toxicity is usually at least 100 times higher than the set MRLs value (Syngenta 2013). However, it is crucial to provide MRLs value to make sure that the pesticides are applied according to the

Table 5-1. DALY estimation from the production supply chains of palm oil industry in Indonesia.

Year	DALY from CO_2 emissions				DALY from CH_4 emissions		DALY from N_2O emissions	
	LUC	Plantation	Transportation	Milling	Transportation	Milling	Transportation	Milling
2004	1038534.4	(279793.6)	1.4	4.7	0.006	0.016	0.024	0.060
2005	127791.1	(34428.4)	1.7	5.7	0.008	0.019	0.029	0.073
2006	211694.6	(89981.0)	1.8	6.0	0.008	0.020	0.030	0.077
2007	234315.1	(90926.6)	2.0	6.6	0.009	0.022	0.033	0.085
2008	386005.5	(133043.9)	2.1	6.9	0.009	0.023	0.035	0.088
2009	638975.7	(203990.7)	2.1	7.1	0.009	0.024	0.036	0.091
2010	1001686.8	(310167.8)	2.2	7.3	0.010	0.024	0.036	0.093
2011	1377368.3	(426666.9)	2.3	7.5	0.010	0.025	0.038	0.096
2012	1629436.0	(518496.4)	2.4	8.0	0.011	0.027	0.040	0.102
2013	1613900.8	(545529.8)	2.6	8.7	0.012	0.029	0.044	0.112
2014	1281140.6	(489617.1)	3.0	9.8	0.013	0.033	0.049	0.125
Total	6418308.5				0.4		1.4	

standard which ensures the food safety for consumer. Consequently, it may allow the agriculture product to be traded internationally if it has already followed the standards.

Although MRLs is intended for the trade standard and insuring whether the pesticides were applied correctly, but the set of MRLs value is a very important effort for the health protection of consumer. Thus, in case the high level of health protection is an aim, such as in EU law that has made the MRLs value of EU is lower than standard value in other countries.

MRLs indicate that the application of pesticide in line with the Good Agriculture Practice (GAP). If the MRLs are exceeded, the further assessment is needed to more understand on its effect to human health. The assessment will involve the measurement of acceptable daily intake (ADI) and acute reference dose (ARfD) because if the two indicators are exceeded, it means that human health concern is arising (ECPA 2014).

5.5 Conclusion

This preliminary comparative study of environmental impact between Indonesian palm oil (IPO) and Japanese green tea (JGT) shows the different crucial issue. The LUC becomes a key issue for the IPO which indicated by the increasing trend of LUC for the palm oil plantation expansion to meet the demand. In case of JGT, the historical data shows that there is no LUC and the tea plantation area is decreasing overtime. Instead of LUC, the important issue in JGT is more to the pesticide residue in its final product, which it is not a concern yet in the palm oil.

Although IPO and JGT have different key environmental issues, both issues culminate on human health and eventually have fallen as global trade barriers. However, they have a different exposure pathway scenario. It is noted that the exposure pathways to evaluate the human health impact category in the palm oil is mainly started from the GHG emissions as a result of the expansion of plantation areas. The GHG emissions then cause the global warming which increases the health risk due to the climate change. As for green tea, the dosage use of pesticide and harvest times in the tea plantation production supply chain are a critical point to control the pesticide residue level of in the final product. A failure to control in this stage is being a pathway to enable people gets contact with the agricultural chemical contamination through ingestion. Because it is believed that green tea has health benefits, green tea products are more demanding. Thus, green tea is available in many countries globally. It means that more people consume green tea with the hidden ingredient, pesticide residue.

Furthermore, it is necessary to measure the environmental impact of the key environmental issues of IPO and JGT by using same end-point indicator of human health, such expressed in DALY. Thus, the level of damage to human health could be directly compared.

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CHAPTER 6

CONCLUSION AND RECOMMENDATION

6.1 Summary

The growing demand for agricultural product has driven the increasing production by exploring natural resources and using agricultural chemicals. As the consequences, the environmental impact of those actions is inevitable. However, the sustainability of agricultural product should be maintained with minimum environmental impact. Therefore, the evaluation of agricultural product by considering supply and demand is necessary. One of the assessment methods is through modeling approach. Number of studies to measure the environmental impact of agricultural product use static modeling such Life Cycle Assessment (LCA) (Meier, 2015). But, it brings a difficulty when there is a limited data available. In addition the static modeling does not emphasize on dynamic supply-demand of agricultural product which is importantly considered, then the effort to meet the demand will not aggravate the environmental impact (Tilman et al, 2002).

Hence, this PhD thesis explains the development and application of modeling for material flow analysis using dynamic approach in agricultural product, particularly in the case of palm oil and green tea. The developed models were able to provide the environmental impact of agriculture production by focus on the production supply-demand chain.

In Chapter 2, we analyzed the impact of the moratorium policy (termed the "MP ", covers MP-1 and MP-2) by focusing on one economic sector that relies on forest conversion and use for its business activities. We developed a model to clarify the impact of MP under reducing emissions from deforestation and forest degradation (REDD-plus) cooperation on the Indonesia's environment and economy using a case study of the palm oil industry sector. An equilibrium supply and demand of palm oil is used as the basis concept of the model. The supply side of the model just covers the fulfillment of required land in order to meet the demand.

By using Business As Usual (BAU) and MP scenarios, this study sought to answer the question what is the future impact of Moratorium Policy on the environment and economy of Indonesia in case of palm oil industry.

Although the model has demonstrated that the MP help to reduce GHG emissions from deforestation, but it was temporary. The environmental degradation may arise again to the next period after the MP finished. Furthermore, the MP reduces CO_2 emissions from deforestation in the range of 7.3% to 24% compare to BAU Level by the year 2020. Thus, although the implementation of MP is until the second phase, the target GHG emission reductions of Indonesia with support from international partners (41%) cannot be attained.

On the other hand, the Indonesia's economic may slowdown as the result of MP implementation since forest conversion and use is the main source of Indonesia economy sector. In case of the palm oil, the industry will experience a breakdown in the production capacity within the range of 1.9% to 4.3%. The production slowdown effect would last sufficiently long when compared to the policy period in the range of 10.5 to 14 years.

The MP can be an initial measure for mitigating GHG emissions from deforestation and forest degradation and give the long-term positive impacts on both economy and environment of Indonesia. However, the further strategy and policy instruments are necessary to prepare before the policy expires. One of strategies that can be performed is establish the degraded lands database for future palm oil plantation expansion in Indonesia. It will give two benefits to Indonesia at once, both for economic growth and environmental amelioration.

We address the model as the simplification of the real system. Despite its limitation which may not exactly match with the actual situation in the future, but the Indonesia economic slowdown is occurred in actual. Furthermore, based on the modeling result, the environmental impact of palm oil plantation due to deforestation can reduce under the MP, but it seems that the implementation of MP will not give more benefit if there is no further policy on it.

Since this first part of this study only explore about trade–off between GHG emissions reduction and economic growth related to MP, the study on other production chain of palm oil industry is needed to understand more on the environmental impact of palm oil which was explain in chapter 3.

Chapter 3 is dealing with developing a model to estimate the historical input-output flow in each production supply chain of palm oil industry. The model is development of the previous model (in chapter 2). The supply side of the model covers the fulfillment of the global palm oil demand based on the IPO's market share in the global market. By using the model, it was possible to estimate and clarify the past environmental loads generated by the production supply chains of palm oil industry in Indonesia in the last decade (2004-2014). The environmental loads that we investigate are particularly for GHG emissions derived from land use change (LUC) and energy use. We also assessed the potential for utilization of fiber and shells waste to generate energy compare to fossil-fuel source.

Based on the modeling result, environmental load for GHG emissions are primarily from the LUC (0.867 Tg CO2eq/year), followed by milling (636.6×10^{-6} Tg CO2eq/year) and transportation production supply chains (192.9×10^{-6} Tg CO2eq/year). About 99% of GHG emissions resulted from the IPO industrial sector is from its LUC production supply chain. Furthermore, it is indicated that the GHG intensity was high during LUC initiation to establish plantation areas but it is gradually decrease due to established plantations, which drive the carbon sequestration. Because the established plantation implies to the carbon sequestration and an increasing FFB yield that eventually palm oil production.

Furthermore, the model demonstrated that the utilization of fiber and shells waste to generate energy has resulted higher GHG emissions compare to the use of fossil fuel-based energy (1.4×10^{-3} Tg CO_2eq /year). It is noted that the outcome obtained only within the boundary of production supply chain process. Within the larger boundary (including the fugitive emissions), the waste utilization to generate energy is still promising to mitigate the environmental load. Thus, the policy for the waste utilization to afford energy in palm oil plantation is needed to be encouraged.

The prototype model in the study was be able to measure the environmental loads of palm oil related to the input-output of land, raw materials (FFB), energy, gases, and solid wastes. The model can be applied for estimate the other environmental loads in palm oil industry. The future study on the environmental load related to human health, such as the use of agricultural chemical, is possible to be clarified by using the development of the prototype model.

In order to know whether the prototype model developed in the study of palm oil can be applied to another agricultural product, we extend and develop the model for Japanese green tea as discussed in chapter 4. Although Japanese green tea is well known product but it cannot enter some countries due to the MRL values of some pesticides are still higher than the CAC or EU. The purpose of the study part is to clarify and estimate exposure pathways of pesticides on tea plantation using a case study of Shizuoka, Japan, and propose the improvement of the Japanese good agricultural practice (GAP).

Despite the studies of pesticide fate and transport is generally performed through field trial, this study use modeling for the estimation. The modeling simulation indicated that the dissipation half-life of pesticides in tea leaves that affect the rate of pesticide degradation, vary according to the timing of pesticide application (1.5–3.9 days for Azoxystrobin and 3.8–9.5 days for Clothianidin). Thus, implementation of a fixed PHI time might not be appropriate if the goal is to decrease the pesticide residues in green tea under desired level.

The model was developed to enhance the understanding of the fate and transport of pesticides in tea plantation areas associated with the application of GAP. The analysis showed that considering specific factor, such as temperature, is important for the PHI. As PHI is one of crucial provision in GAP, it is necessary to deliberate new guidelines regarding the PHI. Furthermore, to produce good-quality, safe green tea, the GAP should provide detailed and precise guidelines on the timing of pesticide applications and formulation of dosage treatments considering specific provisions for the harvest times of fresh tea leaves.

Notwithstanding in the model of this study only include two pesticides, but the model has successfully represented the structure of the real system. Hence, the model can be used to analyze other pesticides with some adjustment.

6.2 Limitation of Study

The model of study, especially for palm oil analysis, uses the concept partial equilibrium for supply-demand in the model. This concept considers that the price of commodity is constant for the customer. Although the model seems a stilted prediction, this study has tried to reduce this limitation by taking into account the dynamic approach and uncertainty in the real system (using normal distribution parameter input). Furthermore, this study has conducted sensitivity analysis for checking limitation of the concept. In addition, the key variables in the model also have been validated based on the real system.

The model of this study has passed through a series of model validation procedures to reveal errors, flaws, limitations, and shortcomings of the model. It includes dimensional consistency, historical reproduction testing, extreme condition testing, univariate sensitivity analysis and multivariate sensitivity analysis. Although model is still a simplification of the real system but the model validation has built confidence that the model is useful to generate insight into and understanding relative to the themes being studied. 'With new insights and better understanding then will come better instincts for managing environmental systems' (Ford 2010).

6.3 Contribution of Study

The model in this study was developed by including the demand and supply of the agricultural product with case studies of Indonesia palm oil (IPO) and Japanese green tea (JGT). Using scenario analysis, the environmental impact of exploring natural resources is represented by IPO while JGT represents the environmental impact due to agricultural chemicals.

The development and application of the model led to specific measurement to accomplish the purpose of this study. Through the model simulation, the critical point to be improved in agriculture production is obtained. The following is the main contribution of this study.

Although the effort to reduce the environmental impact has been done by the implementation of moratorium policy in case of Indonesia palm oil (IPO), the application of the model shows that it will not give a great impact to the reduction of environmental degradation in terms of GHG emissions. In addition, it can contribute to the economic slowdown. This study provides insight and understanding about trade–off between GHG emissions reduction and economic growth related to International Carbon Market-Based Mechanisms through REDD-plus Framework.

For the further understanding of the environmental impact due to exploring natural resources, the developed model in this study has been applied to clarify and estimate the environmental load comes from the palm oil within the boundary of supply chain process. Based on the model simulation, LUC production supply chain is the main source of environmental loads in palm oil for GHG emissions. It implies that, further strategy and policy instruments prepared during the MP implementation is absolutely crucial. For example: to establish the degraded lands database for future palm oil plantation expansion in Indonesia. The industry should shift their method in increasing the production capacity of existing plantations rather than increase forest conversion, such increasing a planting density, using good quality seed.

The model is not only successfully applied for palm oil case but also to green tea as an attempt to measure the environmental impact from the use of agriculture chemicals. By extend and develop the concept of prototype model in palm oil, this study was able to provide insight and understanding about trade–off between the use of pesticides to meet the growing demand for agricultural products and human health. The application of the model demonstrates how the fate and transport of the pesticides in tea plantation, it implies that current Japanese GAP should be revised to meet the MRL standards set by CAC and EU.

The model has been successfully developed and applied to assess different environmental issues in different agricultural products. The model also can be used to provide an overview about the past and future environmental impacts. Furthermore, a series of model validation procedures has built confidence that the model is useful to generate insight into and understanding relative to the themes being studied. Thus, the developed model can be used to provide the basis for clarifying and estimating the environmental impact for other agricultural products, although some adjustments and developments may be necessary.

6.4 Recommendation

Based on this study, the following recommendation may apply:

1. To minimize the environmental impact from agricultural product due to exploring of natural resources, the governance of LUC associated should be priority handled in order to reduce the environmental degradation. The Moratorium Policy is only an initial measure for the governance of LUC. The critical analysis for further policy and strategy which prepared during moratorium policy period is necessary.

2. To minimize the environmental impact from agricultural product due to the use of pesticides or agricultural chemicals, the GAP should provide detailed and precise guidelines on the timing of pesticide applications, formulation of dosage treatments considering specific provisions for the harvest times. Thus, incorporation of factors specific to individual plantations for the GAP guidelines and the PHI that is not implemented at fixed days, are essential to maintain pesticide residues under the desired levels.
3. Developing the model which is able to directly compare the environmental impact of various agriculture products by using the same impact category, such expressed in Disability-adjusted Life Years (DALY), are good for the future work.

APPENDIX

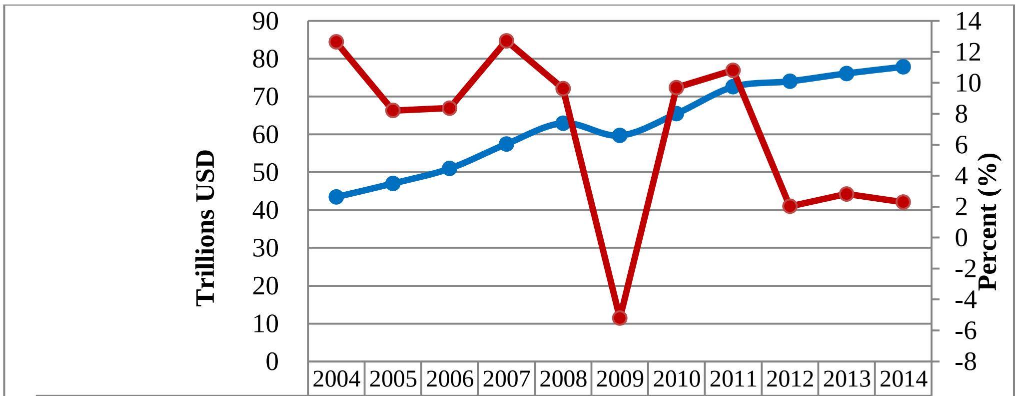
This Appendix presents the representatives of data collection and processing as input for the model, mathematical model of the interrelationships among variables within the model, and quantitative output of the model. Preliminary comparative study about Indonesian palm oil and Japanese green tea are also presented.

A.1 Data input (Chapter 2 and 3)

A.1.1 World Gross Domestic Product

We mainly use historical data for each variable over the 10 years for data input. Data were collected from several online databases. We then processed the data to get mean and standard deviation. For simulating the model, data inputs used mean value only or mean and standard deviation by the given probability distribution (in this study we only use a normal distribution).

The historical data of world GDP and its nominal growth rate for the period 2004-2014 are shown in figure A-1. Based on the data, the total world GDP in 2014 is USD $43.5 trillion. During the period of 2001-2010, the highest and lowest of the increasing nominal rate of GDP were 12.7% and -5%, respectively. The average increase nominal rate of GDP growth from 2004 to 2014 was 6.7% annually (i.e., mean value). The standard deviation of nominal rate of GDP growth using Bessel's correction is 5.6%.



	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
World GDP [USD]	43,464	47,033	50,971	57,452	62,983	59,704	65,489	72,577	74,041	76,123	77,868
Nominal growth rate	12.64	8.21	8.37	12.71	9.63	(5.20)	9.69	10.82	2.02	2.81	2.29

Figure A-1. Historical data of world GDP and its nominal growth rate.

For the model development-II (chapter-II), we used the world GDP data in 2014 (USD $43.5 trillion) as initial condition (t_0) of the stock of world GDP and the mean (6.7%) and standard deviation (5.6%) of nominal rate of GDP growth as parameter that determines stepwise changes in the world GDP (i.e. flow of world GDP increase).

A.1.2 Time Delay for Plantation Establishment and Management

We also collected the required data/information from textbooks, and papers in scientific journals or proceedings. We referred to the Rankine and Fairhurst's Schematic plan (cited in Corley dan Tinker, 2003) for a delay time or transition time of the processes of palm oil plantation establishment (i.e., LUC sub-model) and management (i.e., plantation sub-model).

The Rankine and Fairhurst's Schematic plan may overlap for different processes, but if we split into two major processes is as follows.

(a) The processes of palm oil plantation establishment (surveying, land clearing, roads and drains, LCP, lining) takes around 240 days or 0.66 years in total time.

(b) The processes of palm oil plantation management (nursery processes, planting, care and maintenance, harvesting) takes around 1004 days or 2.75 years in total time.

For the model, we set a delay time or transition time as follows.

(a) Since the process of of palm oil plantation establishment is not only land preparation (surveying, roads and drains, land clearing, legume cover planting , lining), it is also needed a permission from government including to follow the reqired procedures, and to prepare and organize all resources that are needed for it. Thus, for the delay time of land preparation is assumed 365 days or 1 year.

(b) Since it is assumed there are 3 stocks that depict the processes from nursery to harvest processes (new, immature and mature plantations). Thus, we determine the transition time between new to immature and immature to mature plantations are 1 and 1.75 years, respectively.

Table A-1. Schematic plan for a new palm oil plantation.

Task name	Days
Nursery preparation	30
Nursery planting	3
Nursery maintenance	300
Final culling	2
Surveying	30
Roads and drains	120
Land clearing	150
LCP	130
Lining	60
Planting	70
Supply planting	180
Field maintenance	850
Preharvest preparation	30
Scout harvesting	210

(c) The delay time for mature to unproductive plantation or called the productive time is in the range of 22 to 30 years (Yusoff & Hansen 2007)(Abdullah & Sulaiman 2013)(Soraya et al. 2014)(Ling 2012). For the model in chapter-II, we used the shortest time that is 22 years. For the model in chapter-III, a normal distribution from the range is used as input for the model, that is Normal (25, 3.3) years. 25 years are the mean value and 3.3 years are the standard deviation value.

A.1.3 General milling data

General milling data to estimate the input–output flow being evaluated is collected from papers in scientific journals or proceedings that were conducted in Southeast Asia. For example, the oil extraction ratio of CPO from FFB ($CPO_{\text{ratio to FFB}}$) is in the range of 0.168 to 0.22 (Yusoff & Hansen 2007)(Yusoff 2006)(Chavalparit et al. 2006)(Hayashi 2007) (Pleanjai et al. 2007)(Soraya et al. 2014). Normal distribution with the mean value of 0.197 and standard deviation value of 0.022 is used as $CPO_{\text{ratio to FFB}}$ to estimate the CPO production.

A.2 Mathematical model (Chapter 2 and 3)

A.2.1 GDP per capita

As has been described, the demand sub-model describes the population, gross domestic product (GDP), income, consumption, and market share that influence stepwise changes in GPO demand, which eventually drives changes in the IPO industry. Where, the palm oil consumption (POC) per capita is influenced by personal income, which is measured using GDP per capita. The following is explanations of the mathematical equation for GDP per capita.

The *GDP per capita* at time *t* is the *World GDP* at time *t* divided by the *World Population* at time *t*.

$$\text{GDP per Capita (t)} = \frac{\text{World GDP (t)}}{\text{World Population (t)}}$$

Where total *World Population* at time *t* is *World Population Numbers* at initial time (t_0) plus the integration value of *Births* at any time *s* minus the integration value of *deaths* at any time *s* (i.e., time between the initial time and the current/desired time). *Births* at time *t* is the total *World Population* at time *t* multiplied by *Crude Birth Rate*, and *Deaths* at time *t* is the total *World Population* at time *t* multiplied by c*rude death rate*.

$$\text{Population (t)} = \text{World Population at initial time} + \int_{2010}^{t} \text{Births (s) ds} - \int_{2010}^{t} \text{Deaths (s) ds}$$

$$\text{Births (t)} = \text{Total World Population (t)} \times \text{Crude Birth Rate}$$

$$\text{Deaths (t)} = \text{Total World Population (t)} \times \text{Crude Death Rate}$$

and total *World GDP* at time *t* is the *GDP* at initial time plus the integration value of *Increasing GDP* at any time *s*. *Increasing GDP* at time *t* is the total *World GDP* at time *t* multiplied by *Nominal GDP Growth Rate*.

$$\text{World GDP (t)} = \text{GDP in 2010} + \int_{2010}^{t} \text{Increasing GDP(s) ds}$$

$$\text{Increasing GDP (t)} = \text{World GDP (t)} \times \text{Nominal GDP Growth Rate}$$

A.2.2 Effect of GDP per capita on POC per capita

The effect of GDP per capita (i.e., personal income, as independent variable) on POC per capita (as dependent Variable) was estimated using regression analysis based on historical data. The equation of simple linear regression model for two variables is as follows.

$$Y = a + bX$$

$$Y = \frac{\sum_{i=1}^{n} Y - b\left(\sum_{i=1}^{n} X\right)}{n} + \frac{n\sum_{i=1}^{n} XY - \left(\sum_{i=1}^{n} X\right)\left(\sum_{i=1}^{n} Y\right)}{n\left(\sum_{i=1}^{n} X^2\right) - \left(\sum_{i=1}^{n} X\right)^2} \cdot X$$

Where *Y* is *POC per capita* and *X* is *GDP per capita*.

By calculating numerical values that are listed in table A-2, a mathematical equation of the effect of GDP per capita on POC per capita is as follows.

$$\text{POC per Capita (t)} = 0.000995136 + [7.08077 \cdot 10^{-7} \cdot \text{GDP per Capita (t)}]$$

Table A-2.Historical data and element numerical values for regression analysis.

Year	Y = POC per capita [Mg/person]	X = GDP per Capita [USD/person]	XY	X^2
2001	0.0045332	5187.023	23.51365	26905205
2002	0.0049456	5324.105	26.33085	28346096
2003	0.0051811	5916.927	30.65644	35010019
2004	0.0056468	6577.917	37.14432	43268994
2005	0.0060052	7023.533	42.17779	49330019
2006	0.0061726	7520.202	46.41912	56553443
2007	0.0066709	8379.722	55.90031	70219742
2008	0.0070313	9086.052	63.8865	82556340
2009	0.0074007	8491.492	62.84291	72105430
2010	0.0078161	9157.606	71.57657	83861746
Total	0.0614035	72664.58	460.4485	5.48E+08

A.2.2 Carbon Stock calculation in the plantation production stage

The carbon stock estimation also take into account the different age of oil palm crops on the plantation, which split into four stocks of new, immature, mature, and unproductive plantation. The estimation is based on the tier 1 methodology of the IPCC guidelines for National Greenhouse Gas Inventories, as follows.

In Chapter 5 (Cropland), section 5.2 (Cropland remaining Cropland), page 5.7.

The calculation of the biomass carbon stock is, "*To multiply the area of perennial woody cropland by a net estimate of biomass accumulation from growth and subtract losses associated with harvest or gathering or disturbance*".

a. Biomass Accumulation.

- For Immature plantation (refers to section 5.2 -Land Converted to Cropland-), page 5.25).

  "*It is assumed that all biomass is cleared when preparing a site for cropland use, thus, the default for biomass stocks on land after the conversion is 0 tonne C ha^{-1}. In addition, a value is needed for carbon stocks after one year of growth in crops planted after conversion (ΔC_G). Table 5.9 provides defaults for ΔCG. Default values provided in this section are for one year of growth immediately following conversion*".

  Immature plantation is 1 year (i.e., delay/transition time) after new plantation. Therefore, biomass in the immature plantation is estimated using the ΔC_G default value for *perennial cropland and climate region of tropical wet* (Table 5.9, page 5.28). That is 10 Mg C ha^{-1} (in this paper, see Table 3-1, item 20). The following is the equation:

  $$\text{Biomass in the immature plantation (t)} \quad = \text{Immature area (t)} \times \Delta C_G$$

  Please check Table 2-1 item 16 for the equation of Immature area (t).

- For mature plantation

  Because there is no data availability for the growth of carbon stocks for palm oil crops from immature to mature, we assumed it is same with ΔC_G. Thus, the equation is as follow.

Biomass in the mature plantation (t)	= Mature area (t) × 10 Mg C ha^{-1} $year^{-1}$

Please check Table 2-1 item 18 for the equation of Mature area (t).

b. Biomass losses

Annual pruning in the mature plantation and felling for replanting in the unproductive plantation are considered as a biomass losses in this study. It also is considered and main solid waste that are generated in the plantation production chain (see the paper, page: 4 line 10-11). Annual pruning will generate frond (in this paper, see Table 1, item 27). Felling for replanting will generate frond and trunk (in this paper, see Table 1, item 28 & 29)

Under the scenario circumstances above, the biomass accumulation occurs in the immature and mature plantation area. Thus, net biomass accumulation (i.e., "…*accumulation from growth subtract losses associated with*…") is as follows.

Carbon stock in biomass in the plantation area (t)	= Biomass in the immature plantation (t) + Biomass in the mature plantation (t) - Biomass Losses from Annual Pruning (t)
Biomass Losses from Annual Pruning (t)	= Mature area (t) × Frond from annual pruning × Default value carbon fraction of dry matter

A.3 Quantitative Output of the Model

A.3.1 Simulation result for the palm oil global demand in chapter 2.

The model extrapolates that,

- The world population was 6.9 billion people in the year 2010. It projected will be reached 7.8 billion people by the year 2020. It will be around 1.13 times higher than in 2010 or has increased by around 13% in total within 10 years (2010-2020).
- The world GDP will reaches USD $128 trillion in 2020 or it is around 2 times higher than in 2010. This trend actualy is same with the period 2000 to 2010, that is USD $32 trillion in 2000 grew to 63 Trillion USD in 2010.

- The GDP per capita is projected will be 1.8 times higher than in 2010 that is approximately will be USD $16462 per Capita in 2020.
- Level of income is estimated will affect to the POC of around 0.0127 Mg per capita or 12.7 kg per capita in 2020.

Thus, the total GPO demand in 2020 is projected to reach 98. 1×10^6 Mg, whereas the total IPO demand is estimated to be approximately 52×10^6 Mg in 2020. The result corresponds to the GAPKI prediction regarding the production capacity that the IPO should have by 2020 in order to meet the demand (The Jakarta Post 2010).

Table A-3.Projection of the global palm oil demand determined by world economic and demographic situations.

Year	World Population (person)	World GDP (USD)	GDP per Capita (USD per person)	POC per Capita (Mg per person)	GPO demand (Mg)
2010	6.89E9	6.31E13	9157.61	0.0075	5.16E7
2011	6.98E9	6.78E13	9710.75	0.0079	5.49E7
2012	7.06E9	7.27E13	10297.3	0.0083	5.85E7
2013	7.15E9	7.8E13	10919.3	0.0087	6.24E7
2014	7.23E9	8.38E13	11578.8	0.0092	6.65E7
2015	7.32E9	8.99E13	12278.2	0.0097	7.09E7
2016	7.41E9	9.65E13	13019.8	0.0102	7.57E7
2017	7.5E9	1.04E14	13.806.3	0.0108	8.08E7
2018	7.59E9	1.11E14	14640.2	0.0114	8.62E7
2019	7.68E9	1.19E14	15524.5	0.012	9.21E7
2020	7.77E9	1.28E14	16462.2	0.0127	9.83E7

A.3.2 Simulation result for the figures shown in chapter 3.

Table A-4. Detailed quantitative estimation of changes in Global warming potential resulted from the IPO industrial sector for the time period 2004-2014 that is shown by Figure 3-5.

Year	Flow of GHG emissions ($Tg\ CO_2eq$)	Flow of carbon sequestration ($Tg\ CO_2eq$)	Stock of GHG emissions in the atmosphere ($Tg\ CO_2eq$)
2004	1.04	0.28	0.76
2005	0.13	0.03	0.85
2006	0.21	0.09	0.98
2007	0.24	0.09	1.12
2008	0.39	0.13	1.37
2009	0.64	0.20	1.81
2010	1.00	0.31	2.50
2011	1.38	0.43	3.45
2012	1.63	0.52	4.57
2013	1.61	0.55	5.63
2014	1.28	0.49	6.43

Note: The stock of net GHG emissions in the atmosphere is a cumulatively balance between the flow of GHG emissions and carbon sequestration. Until 2014, The stock (total) of GHG emissions and carbon sequestration resulted from the IPO production chain activities are 9.55 and 3.12 Tg CO_2eq, respectively. Thus, carbon sequestration contributed to reduce nearly one-third of total GHG emissions.

Table A-5. Detailed quantitative estimation of changes in the GHG intensity of palm oil over time that is shown by Figure 3-6.

Year	Stock of GHG emissions in the atmosphere ($Mg\ CO_2eq$)	Flow of palm oil production (Mg)	Stock of palm oil production (Mg)	GHG intensity of palm oil ($Mg\ CO_2eq$/Mg palm oil)
2004	759291.6	0.0	0.0	undefine
2005	853320.0	0.0	0.0	undefine
2006	975731.2	0.0	0.0	undefine
2007	1119891.4	2220124.8	2220124.8	0.504
2008	1373657.3	3296462.8	5516587.6	0.249
2009	1809469.6	4030863.2	9547450.9	0.190
2010	2501836.1	4699080.5	14246531.3	0.176
2011	3453415.6	5634379.7	19880911.0	0.174
2012	4565286.0	7181006.2	27061917.2	0.169
2013	5634674.3	9715560.0	36777477.2	0.153
2014	6427341.4	13411691.5	50189168.6	0.128

Table A-6. Detailed quantitative estimation of the surplus energy from fibre and shell utilization in the IPO industrial sector that is shown by Figure 3-7.a.

Year	Annual required energy (TJ)	Annual energy conversion (TJ)	Stock of surplus energy (TJ)
2004	7364	124143	116778
2005	8898	149996	257876
2006	9321	157131	405686
2007	10299	173608	568995
2008	10718	180647	738924
2009	11002	185376	913297
2010	11255	189549	1091592
2011	11640	195927	1275879
2012	12300	206935	1470514
2013	13387	225157	1682283
2014	14972	251776	1919087

Table A-7. Detailed quantitative estimation of fibre and shell to balance the required energy and its GHG emissions that is shown by Figure 3-7.b.

Year	Required Fibre (Mg)	Required Shell (Mg)	GHG emissions of Fibre Fuel (Tg CO_2eq)	GHG emissions of Shell Fuel (Tg CO_2eq)
2004	575089	246467	9.95E-04	4.73E-04
2005	694886	297808	1.20E-03	5.72E-04
2006	727920	311966	1.26E-03	5.99E-04
2007	804296	344698	1.39E-03	6.62E-04
2008	837018	358722	1.45E-03	6.89E-04
2009	859197	368227	1.49E-03	7.07E-04
2010	878955	376695	1.52E-03	7.23E-04
2011	909021	389580	1.57E-03	7.48E-04
2012	960564	411670	1.66E-03	7.90E-04
2013	1045452	448051	1.81E-03	8.60E-04
2014	1169232	501100	2.02E-03	9.62E-04

Table A-8. Detailed quantitative comparison of the GWP resulted from the IPO production supply chain activities using a different energy source (i.e., fossil fuels and waste utilization) that is shown by Figure 3-8.

Year	Stock of GHG emissions in the atmosphere from fossil fuel-based energy (Tg CO_2eq)	Stock of GHG emissions in the atmosphere from waste utilization-based energy (Tg CO_2eq)	GHG emissions difference (Tg CO_2eq)
2004	0.759	0.760	0.001
2005	0.853	0.855	0.002
2006	0.976	0.979	0.003
2007	1.120	1.124	0.004
2008	1.374	1.379	0.006
2009	1.809	1.817	0.007
2010	2.502	2.510	0.009
2011	3.453	3.463	0.010
2012	4.565	4.577	0.012
2013	5.635	5.648	0.013
2014	6.427	6.442	0.015

The following is an example calculation why in this study, the GHG emissions from solid waste are higher than those from fossil fuels.

Energy recovery from fiber and shell utilization in this study referred to Mahlia et al. (Mahlia et al. 2001), efficiency of energy conversion is 68% and the actual fibre-shell fuel is comprised of 70% fiber and 30% shell. The example calculation below is for Annual required energy in 2014 (14972 TJ; Table A-6.).

- Total amount fibre and shell fuels to generate the required energy:

  = the required energy in 2014/ [(70% × LHV_{Fibre} + 30% × LHV_{Shell}) × Efficiency of energy conversion]

  = 14972 TJ / (0.0079268 + 0.0052548) TJ/Mg × 68%

  = 1670331.9 Mg

  Thus, the required fibre and shell in 2014 is 1169232 Mg and 501100 Mg, respectively.

- Total GHG emissions resulted from the energy recovery from Fibre and Shell fuels:

  = (Required fibre × CO_2 emissions factor for fibre combustion + Required shell × CO_2 emissions factor for shell combustion) × CO_2 GWP/1000

  = (1169232 Mg Fibre × 1.73 Mg/Mg Fibre + 501100 Mg Shell × 1.92

Mg/Mg Shell) × 0.001

= (2022771.4 + 962112) × 0.001

= 2984.9 $MgCO_2eq$ ~ 2.98E-03 $TgCO_2eq$

While for a combustion of diesel full will generate CO_2 emissions:

= the required energy in 201 × CO_2 emissions factor for diesel combustion × CO_2 GWP/1000

= 14972 TJ × 74.1 Mg/TJ× 0.001

= 1109.4 $MgCO_2eq$~ 1.11E-03 $TgCO_2eq$

A.3.3 Simulation result for mass balance of the pesticides in chapter 4.

Table A.9. Quantitative information per month in both compartment and flow for the sub-model of tea plant developmental stages (that is shown by Figure 4-3).

Month	New Tea Plant (ha)			Immature Tea Plant (ha)		Mature Tea Plant (ha)		
	Input	Compartment	Output / Input	Compartment	Output / Input	Compartment	Output	
	Replanting		Seedling to Immature Growth		Immature to Mature Growth		Replanting	Abandon
January	39.2	38.8	0.4	196.1	5.6	18047.5	39.2	17.7
February	39.0	76.6	1.2	191.8	5.5	17996.3	39.0	17.7
March	38.9	113.4	2.0	188.4	5.4	17945.1	38.9	17.6
April	38.8	149.4	2.8	185.9	5.3	17894.0	38.8	17.6
May	38.6	184.5	3.5	184.2	5.2	17843.1	38.6	17.6
June	38.5	218.8	4.3	183.3	5.2	17792.2	38.5	17.5
July	38.4	252.2	5.0	183.1	5.2	17741.5	38.4	17.5
August	38.3	284.7	5.7	183.6	5.2	17691.0	38.3	17.5
September	38.1	316.5	6.4	184.7	5.2	17640.6	38.1	17.4
October	38.0	347.4	7.0	186.5	5.3	17590.5	38.0	17.4
November	37.9	377.6	7.7	188.9	5.3	17540.5	37.9	17.4
December	37.7	407.0	8.3	191.8	5.4	17490.8	37.7	17.4
Per Year	461.3		54.3		63.8		461.3	210.3

Table A-10. Quantitative information per month in both compartment and flow for Azoxystrobin in the pesticide fate and transport sub-model (that is shown by Figure 4-3).

Month	Applied Pesticide (Total Input)	Soil (kg)				Tea Leaves (kg)			
		Input	Compartment	Output		Input		Compartment	Output
		Fraction to soil		Uptake by tea plants	Degradation	Fraction to leaves	Uptake by tea plants		Degradation
January	3619.7	1452.1	856.6	69.6	525.9	2167.6	69.6	21.1	2216.1
February	3609.5	1448.0	1350.8	111.5	842.4	2161.5	111.5	25.5	2268.6
March	3599.3	1443.9	1634.7	135.6	1024.4	2155.3	135.6	21.2	2295.3
April	3589.0	1439.8	1796.9	149.4	1128.3	2149.2	149.4	16.0	2303.8
May	3578.8	1435.7	1888.5	157.1	1187.0	2143.1	157.1	13.3	2302.9
June	3568.6	1431.6	1939.2	161.4	1219.5	2137.0	161.4	11.6	2300.1
July	3558.4	1427.6	1966.2	163.7	1236.9	2130.9	163.7	9.9	2296.4
August	3548.3	1423.5	1979.4	164.9	1245.4	2124.8	164.9	9.3	2290.2
September	3538.2	1419.4	1984.7	165.3	1248.8	2118.8	165.3	10.7	2282.7
October	3528.1	1415.4	1985.3	165.4	1249.3	2112.7	165.4	13.9	2274.9
November	3518.1	1411.4	1983.4	165.2	1248.1	2106.7	165.2	18.7	2267.1
December	3508.1	1407.4	1979.8	164.9	1245.9	2100.7	164.9	27.8	2256.6
Per Year	42764.2	17155.9		1774.1	13402.0	25608.3	1774.1		27354.6

Table A-11. Quantitative information per month in both compartment and flow for Clothianidin in the pesticide fate and transport sub-model (that is shown by Figure 4-3).

Month	Applied Pesticide (Total Input)	Soil (kg)				Tea Leaves (kg)			
		Input	Compartment	Output		Input		Compartment	Output
		Fraction to soil		Uptake by tea plants	Degradation	Fraction to leaves	Uptake by tea plants		Degradation
January	5791.6	2323.4	2114.0	125.5	83.9	3468.1	125.5	418.9	3174.7
February	5775.2	2316.9	4025.5	242.9	162.5	3458.3	242.9	499.9	3620.3
March	5758.8	2310.3	5753.2	349.1	233.5	3448.5	349.1	429.4	3868.1
April	5742.4	2303.7	7314.2	445.0	297.7	3438.7	445.0	304.7	4008.4
May	5726.1	2297.2	8724.2	531.6	355.6	3428.9	531.6	229.0	4036.3
June	5709.8	2290.6	9997.0	609.8	407.9	3419.2	609.8	188.3	4069.7
July	5693.5	2284.1	11145.6	680.4	455.1	3409.4	680.4	153.7	4124.5
August	5677.3	2277.6	12181.4	744.1	497.7	3399.7	744.1	150.6	4146.8
September	5661.1	2271.1	13115.0	801.4	536.1	3390.0	801.4	194.3	4147.7
October	5645.0	2264.6	13955.9	853.1	570.6	3380.4	853.1	296.6	4131.1
November	5629.0	2258.2	14712.8	899.6	601.8	3370.8	899.6	450.2	4116.7
December	5613.0	2251.8	15393.4	941.4	629.7	3361.2	941.4	671.0	4081.8
Per Year	68422.7	27449.5		7223.9	4832.2	40973.3	7223.9		47526.1

A.4 Sensitivity Analysis (Chapter 2 and 4)

Real system is full of uncertainties, the same thing obviously happens for a model that is made as a substitute of the real system. Since the model is a simplification of the real system, the uncertainty sources of the model mainly come from inadequate model structure and parameter data input which are based on the modeler's argument to describe the real system. However, uncertainty related to the model structure frequently reflects disagreements between modelers or experts about the underlying scientific theory or technical mechanism. In this way of thinking, therefore we can convert the uncertainty of the model into the uncertainty of those parameter data inputs [Morgan and Henrion, 1990].

Table A-12. Shizuoka's monthly maximum, average, minimum temperatures.

		Maximum temperature (°C)	Average temperature (°C)	Minimum temperature (°C)
January		11.5	6.7	1.8
	% Difference	71.6		73.1
February		12	7.3	2.5
	% Difference	64.4		65.8
March		14.8	10.3	5.7
	% Difference	43.7		44.7
April		19.5	14.9	10.4
	% Difference	30.9		30.2
May		23	18.8	14.7
	% Difference	22.3		21.8
June		25.7	22	18.8
	% Difference	16.8		14.5
July		29.5	25.7	22.7
	% Difference	14.8		11.7
August		30.8	27	23.8
	% Difference	14.1		11.9
September		27.9	24.1	20.8
	% Difference	15.8		13.7
October		23.1	18.9	15
	% Difference	22.2		20.6
November		18.4	13.9	9.4
	% Difference	32.4		32.4
December		14	9	4.1
	% Difference	55.6		54.4

The principle for sensitivity analysis testing using either univariate (a single parameter) or multivariate (combination of parameters), is the parameter should within the plausible range of uncertainty. To do so, this study consistently uses the values of parameter data that are based on their historical data for conducting the sensitivity analysis in chapter 2 section 2.3.2 and chapter 4 section 4.3.4.

For chapter 4 section 4.3.4, sensitivity analysis is conducted by varying the parameters with the same amount to low (90%) and high (110%) levels of their nominal values. From the simulation result, actual temperature is most parameter that has a significant effect on the pesticide residue in crude green tea. Table A-12 shows the historical data of actual temperature in Shizuoka prefecture, where average temperature is used for simulating the model. Considering the percentage different between maximum and minimum of their average temperature, it shows that the sensitivity analysis testing that is conducted by this study is still under the plausible range of uncertainty.