The Formulation of Sustainable Replanting Policies in the Indonesian Rubber Industry Supply Network

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Intellectual Property and Publication Statements

The Candidate confirms that the work submitted is his own except where the work that has formed part of jointly authored publications has been included and that appropriate credit has been given where reference has been made to the work of others. The contribution of the candidate and the other authors to this work has been explicitly indicated below.

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The candidate performed the major tasks of the work presented in these published papers, such as development of simulation models, simulation experiments, data analysis and the results. The co-authors reviewed and guided the candidate and provided valuable feedback.

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Abstract

The Indonesian natural rubber industry is facing a reduction of natural rubber supply because many rubber plantation areas are entering their low-productive phase. There are significant opportunities to sustain future supplies by managing the replanting of these low-productive areas. Early discussions with Indonesian stakeholders in Northern Sumatera indicated a demand for strategic planning tools to support decisions related to replanting and described significant effects of replanting to the whole region and individual players within the network. The examples of these effects include the level of future supply from the region and the flow of natural rubber between players, which in turn affects income of these players. In addition, a key finding from a review of literature indicated the importance of integrating three dimensions of sustainability (economic, environmental and social) in planning for future supply networks. The aim of this research was to explore ways in which social, economic and environmental aspects of sustainability can be used to inform decisions related to the formulation of replanting policies.

This research contributes a sustainability assessment and optimisation method for use in the formulation of sustainable replanting policies. The sustainability assessment method consists of suitable sustainability indicators and an integrated assessment tool. Indicators at district and individual levels for three dimensions of sustainability were identified through case study investigation and a review of literature. A combination of system dynamics and agent-based simulation was developed as the integrated assessment tool, which demonstrates an ability to assess long-term sustainability impacts of replanting at district and individual levels. The optimisation method was developed to enable the used of the integrated assessment tool to inform the formulation of replanting policies, comprising a combination of composite indicators and dynamic programming. Composite indicators were used to translate sustainability impacts of replanting calculated using the integrated assessment tool into indices of replanting impacts and dynamic programming was used to determine optimum replanting policies using these indices. The application of the method using real world data demonstrated the process of formulating sustainable replanting policies for the North Sumatera Natural rubber industry.

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Chapter 1
Introduction

Natural rubber contributes enormously to the quality of human life and is an essential material that has revolutionized the transportation, manufacturing, and health sectors. Developments in vulcanization processes have resulted in the material exhibiting hyper elastic and durable properties. This development has opened up opportunities for its wider utilization. In the transportation sector, increases in the use of land transport vehicles such as cars, buses, trucks, motorcycles, and bicycles have created the mass consumption of tyres. In the manufacturing sector, rubber has delivered crucial improvements to machine processes through damping and vibration isolation. In the healthcare sector, latex has been extensively used as a raw material for medical and laboratory devices such as stethoscope hoses, pipettes, and gloves. These various uses have contributed to heightened demands for natural rubber.

The European Tyre and Rubber Manufacturing Association (ETRMA) has seen an increasing trend of natural rubber consumption since 2004. This is shown in Figure 1.1, which shows that global consumption of rubber increased from around 8 million tons in 2004 to around 12 million tons in 2014. Approximately 70% of natural rubber production is allocated for tyre production. With the increasing use of cars, aeroplanes, motorcycles, agricultural tractors, and bicycles, the demand for tyres is expected to increase in the future. Moreover, the demand for other rubber products is projected to increase owing to the globally expanding human population.

Heightened demands for natural rubber must be satisfied with increased natural rubber production. Accordingly, the production of natural rubber has increased significantly. Natural rubber is produced from the *Havea Brasiliensis* tree, which grows in tropical climates. Countries with tropical climates such as Indonesia, Thailand, Malaysia, and Vietnam are thus ideal for rubber tree growth. These countries comprise the main suppliers of natural rubber globally. Indonesia and Thailand are the biggest suppliers, producing around 60% of the world’s natural rubber supply. These countries have succeeded in increasing natural rubber production over the last ten years to satisfy heightened demand.

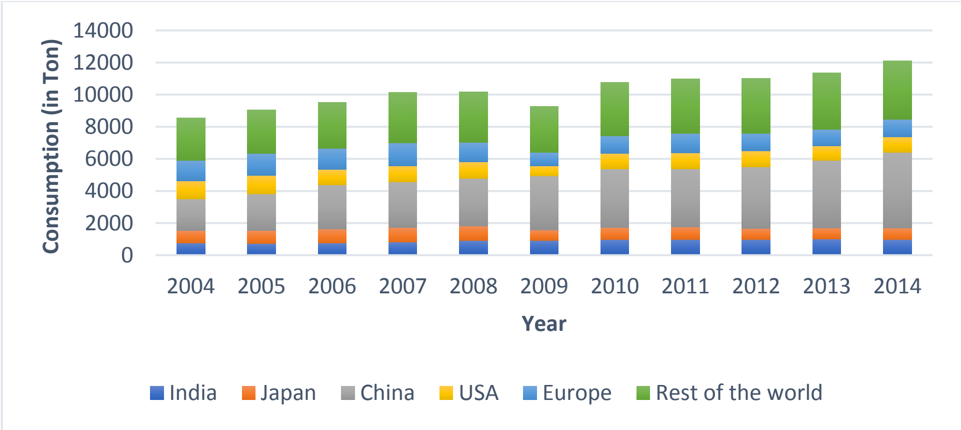

Figure 1.1 Global Natural Rubber Consumption (ETRMA)

This shows the importance of Indonesia in managing the global natural rubber supply. However, effective planning for the management of natural rubber supplies are needed in the Indonesia natural rubber supply network, particularly given threats such as climate change (which has resulted in persistent rain in Sumatera (Indonesia)) and trends for rubber plantations to be replaced by palm oil plantations (Mooibroek, 2010). Further characteristics of rubber plantations, which have long life cycles with varying productivity at each phase, have prompted natural rubber stakeholders to seek appropriate planning systems to sustain the natural rubber supply.

Replanting is an important activity to sustain natural rubber supplies from existing natural rubber plantations because it replaces low productive rubber trees with fully productive rubber trees. However, to become fully productive, a rubber tree needs around six years. This delay brings significant impacts to the sustainability of the supply network. One of the main impacts is the reduction of supply owing to the absence of any production of natural rubber within the six years immature phase after replanting. Furthermore, environmental and social impacts also occur as a result of replanting. The reduction of carbon stocks and the declining population of tappers are example of environmental and social impacts from replanting. This research explored ways in which these aspects of sustainability can be used to inform decisions related to the formulation of replanting policies.

1.1 Sustainability in the natural rubber industry

A renewable source, rubber tree, is an integral part of natural rubber industry. The raw material in this industry is produced on rubber plantations. A range of environmental problems is found owing to the scale of industrial activities. These problems include deforestation, land pollution from fertilizers, and water pollution.

Moreover, social sustainability is also compromised, with human rights violations, poor working conditions, and low wages emerging across the supply network. To address these issues, stakeholders across the industry have opened discussions for innovations to deliver sustainable improvements. However, different approaches are needed at each stage in the supply network, because each stage involves different activities carried out by different people or agents. Figure 1.2 illustrates current innovations and opportunities to improve sustainability in the natural rubber industry that have been identified by International Rubber Study Group (IRSG) and the European Tyre and Rubber Manufacturing Association (ETRMA).

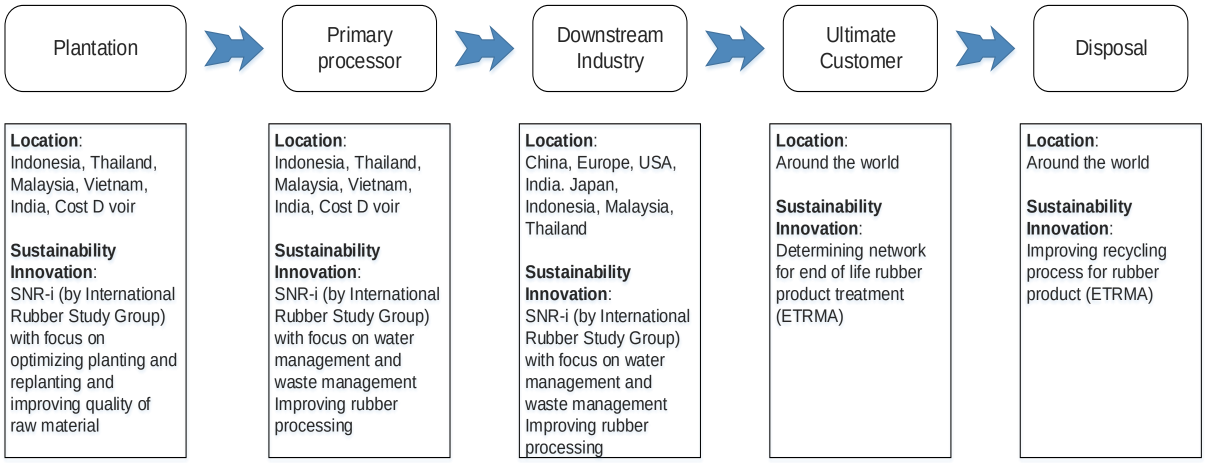

Figure 1.2 Current Innovations and Opportunities to Improve Sustainability in the Natural Rubber Industry (by IRSG and ETRMA)

At the plantation stage, the main target for activities is the production of latex and the supply of latex to primary processors. A challenge at this stage is to define and operate optimum replanting for the sustainable supply of latex {Sustainable Natural Rubber Initiative (SNR-i) by International Rubber Study Group (IRSG)}. Current approaches focus on the use of recommended clones of rubber trees. Several rubber plantations have applied non-recommended clones and, as a result, have a lower productivity level than average. Another target at this stage, as defined by IRSG, is to improve replanting density, i.e., the total of rubber tree per hectare. Normally, a good planting density is between 400 to 600 rubber trees per hectare. However, in many rubber plantations, abnormal planting densities are found in several areas. These abnormal densities can reduce the productivity of plantations. Moreover, defining optimum allocation of replanting is nevertheless challenging while rubber plantations are scattered across different locations, thereby complicating supply networks. Indeed, these plantations may all be in different phases of their life cycle.

Every stage in the natural rubber supply network presents an opportunity for innovations. This thesis focuses on improving sustainability at the plantation tier, which comprises the backbone of the natural rubber industry by producing the raw material latex. Innovation at this stage not only impacts regions with natural rubber plantations but also reduces risks for the natural rubber downstream industry. Effective planning to achieve optimum allocation of replanting requires decision support tools that provide perspective across multiple plantations and the wider supply network.

1.2 Indonesian natural rubber industry

Indonesia has the biggest areas of rubber plantation in the world, producing around 25 % of the global natural rubber supply. Natural rubber is an important natural resource for Indonesia generally, particularly for some specific provinces and districts, contributing 5.94% of total Indonesia Gross Domestic Product (GDP) in 2010. This increased significantly from only 2.1% of total Indonesia GDP in 2001. Although the volume of export for natural rubber remains constant at around 2,600 M Tonnes at 2011-2016, contribution to Indonesia economy decreased in 2014-2015 owing to the declining of rubber price. The contribution of natural rubber to Indonesian GDP was mainly sustained by increased natural rubber production per hectare and inflating rubber prices.

Indonesia is located in South East Asia between the Indian and Pacific Oceans. Owing to its location on the equator, all of Indonesian territory has a tropical climate split between two seasons, a summer season between March and August, and a rainy season from September to February. These climatic conditions make the country a suitable place for growing many industrial crops, including cocoa, palm oil, and natural rubber. Figure 1.3 shows a map of Indonesia.

According to Indonesia's Ministry of Agriculture, rubber plantation areas have remained constant since 2000 at around 3 million hectares. At the same time, the levels of production at rubber plantations have steadily improved up to 2013, although there were slight reductions in 2002 and 2009. As can be seen in Figure 1.4, production increased from 2009's 2,440,410 tons to more than 3,000,000 tons in 2013. This trend is detected in smallholder rubber plantations. Concurrently, the production levels at private and state-owned rubber plantations were constant, giving approximately 500,000 tons. More than 80% of Indonesia's rubber plantations are owned by smallholders with areas of less than 4 hectares per smallholder.

Figure 1.3 Map of Indonesia (source: www.kemenperin.go.id)

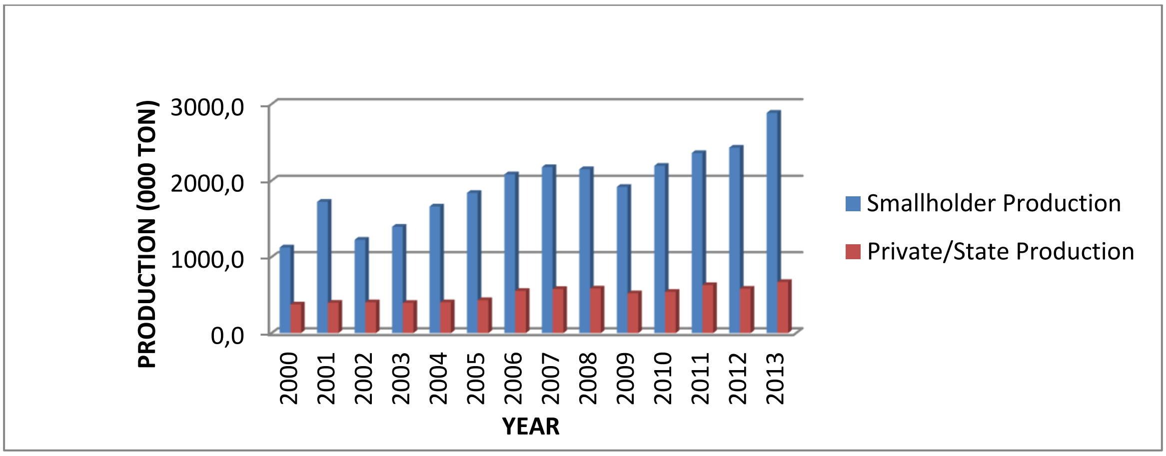

Figure 1.4 Latex production from rubber plantations in Indonesia

Indonesia's natural rubber industry is dominated by rubber plantations and primary processors, which are scattered across provinces and districts. In contrast, there is less downstream industry located across the country with approximately 15% of Indonesian latex is processed in Indonesia's downstream industries. Latex suppliers operating between rubber plantations and primary processors have the responsibility to deliver latex to the primary processors. The various connections between rubber plantations, suppliers, and primary processors located in different districts or provinces, generate a complex supply network for the natural rubber industry. Figure 1.5 illustrates this complexity.

Indonesian territory influences the construction of natural rubber suppliers, from rubber plantation to primary processor. Based on discussions with natural rubber stakeholders and observations of the industry, configurations of upstream Indonesia natural rubber supply networks consist of village suppliers, district suppliers, and traders (Arifin, 2005). The main function of a village supplier is to collect latex (raw material) from rubber smallholders. Usually, every village has one to ten village suppliers, depending on the total natural rubber production of the given village. The next level of supplier is the district supplier. The function of this type of supplier is to collect latex from village suppliers. District suppliers are usually located at sub-district capitals or district capitals. Traders occupy the top level of the supplier hierarchy, receiving latex from district suppliers. Traders are usually located at primary processors. Traders are representative of primary processor to manage supply from several districts suppliers from various districts.

Indonesia's natural rubber industry has specific characteristics, which differentiate it from the natural rubber industry in other countries such as Thailand, Malaysia, and India, the main difference being the configuration of its supply network. In Indonesia, plantations and primary processors are scattered across different provinces and different islands, while in other countries, plantations tend to be centred within specific location. Furthermore, in Indonesia, the behaviour of smallholders is mainly influenced by local culture and habits, which in turn influencing the productivity of plantations. Table 1.1 shows similarities and differences between the natural rubber industry in Indonesia and that of Thailand, Malaysia and India.

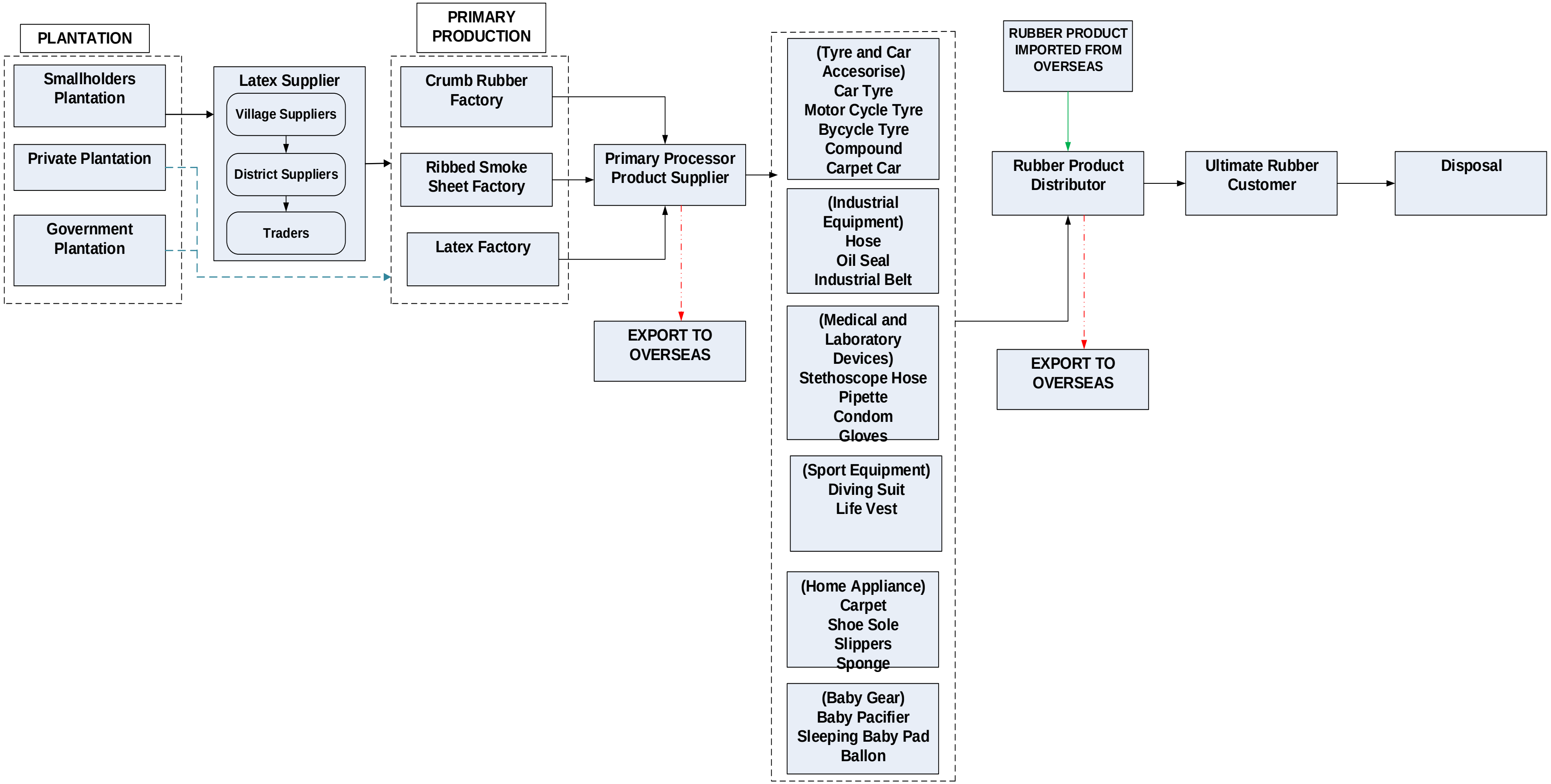

Figure 1.5 Indonesia's natural rubber supply network

Table 1.1 Comparison between natural rubber industry in Indonesia's and other countries' natural rubber industries

No	CHARACTERISTIC	INDONESIA	THAILAND	MALAYSIA	INDIA
1	Owner of Plantation	85% belong to smallholders, 15% belong to private company and state owned company	93% belong to smallholders and 7% belong to private company	8% belong to Malaysia, 90% belong to smallholders and 2% belong to private company	88% belong to smallholders
2	Productivity	Less than 1000 kg per year	Around 1200 kg per year	Around 1200 kg per year	Around 1800 kg per year
3	Supply channel	Plantation-Village collector-middleman-trader	Plantation-central rubber market, cooperative, merchandiser-primary processor-secondary processor	Plantation-trader	Through different channel depending on the product. E.g., For example, rubber sheet distributed through village level dealers to the processor.
4	Location of Plantation	Scattered in different islands, different provinces and districts	In one area, mostly in south of Thailand	In one island	In one area, 78% of rubber plantation is at Kerala
5	Quality product	Various quality with most following Standard Indonesia Rubber (SIR)	Standard Thailand Rubber (STR)	Standard Malaysia rubber (SMR)	Follow India standard rubber (INSR)
6	Primary Processor	Dominated by crumb rubber processor, Rubber smoke sheet and High Concentrated Latex	Dominated by crumb rubber processor, RSS, high concentrated latex and compound	Dominated by standard Malaysia Rubber, Latex and RSS (Rubber smoke sheet)	Dominated by crumb rubber processor
7	Secondary Processor	Dominated by tyre and gloves processor	Tyre tubes for vehicles and aeroplanes, gloves, condoms, rubber bands and elastic	Latex gloves, catheters and latex thread, footwear, tyre and inner tubes	Auto tyre and tubes, bicycle tyre and tubes, footwear, belt and hoses.
8	Consumption of Natural Rubber	85% is being exported, 15% being processed in Indonesia	90 % is being exported, 10% are being processed in Thailand	61% is being exported, 39 % being processed in Malaysia	3% is being exported, and 97% are being processed in India

1.3 Problem Definition, Research Aim and Objectives

This research used the natural rubber supply in North Sumatera Province as a case study because the reduction of natural rubber supplies is occurring in this province. According to the Indonesia Rubber Primary Processor association (GAPKINDO), the reduction of output from plantations in North Sumatera Province has occurred over the last decade. Early discussions with stakeholders from North Sumatera indicated that the reduction of supply has been caused by many plantations entering a low-productive phase at the same time, and many rubber smallholders switching from rubber to other crops on their plantations.

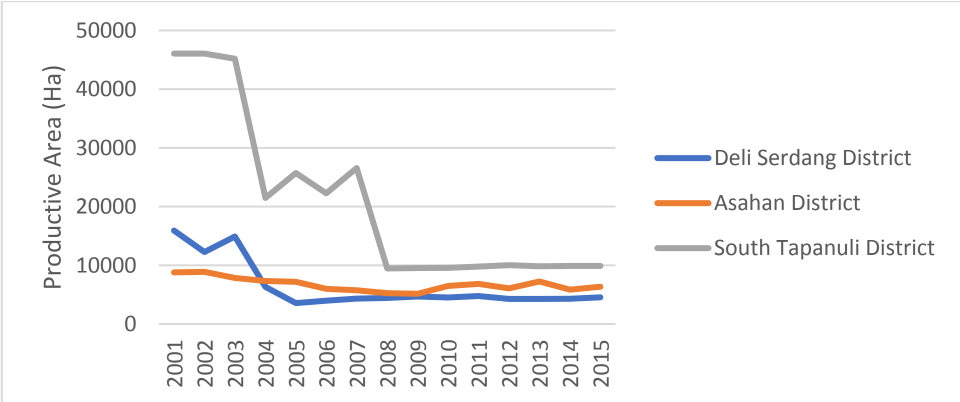

Figure 1.6 Total Productive Areas in Three Districts in North Sumatera Province 2001-2015

Statistical data from these districts in North Sumatera confirm this reduction of supply. This can be seen in Figure 1.6, where reduction of productive areas has occurred in three districts: Deli Serdang District, Asahan District, and South Tapanuli District. Overall, the graph in Figure 1.6 shows that, since 2004, many productive areas have experienced lower production. Furthermore, the majority of low-productive areas have not returned to levels of high production.

1.3.1 Problem Definition

Replanting is the activity of replacing low-productive rubber trees with new rubber trees and the key activity to sustain natural rubber supplies from existing rubber plantations. Rubber trees have a long life cycle consisting of three phases; the immature phase, the productive phase, and the low-productive phase as shown in Figure 1.7. Productivity in each phase varies with no production during immature phase.

In order to meet future natural rubber demands, effective planning regarding replanting is vital. One important and strategic decision in planning replantation is determining the optimum allocation of replanting within a given supply network.

Allocation in the replanting process influences the composition of immature, productive, and low-productive areas, as well as the distribution of rubber age within the network. This in turn affects the capacity of plantations to supply natural rubber for current and future demand, and affects other sustainability levels in the supply network. The allocation of replanting for each area or district within the network can vary owing to the different conditions of rubber plantation areas in a given district.

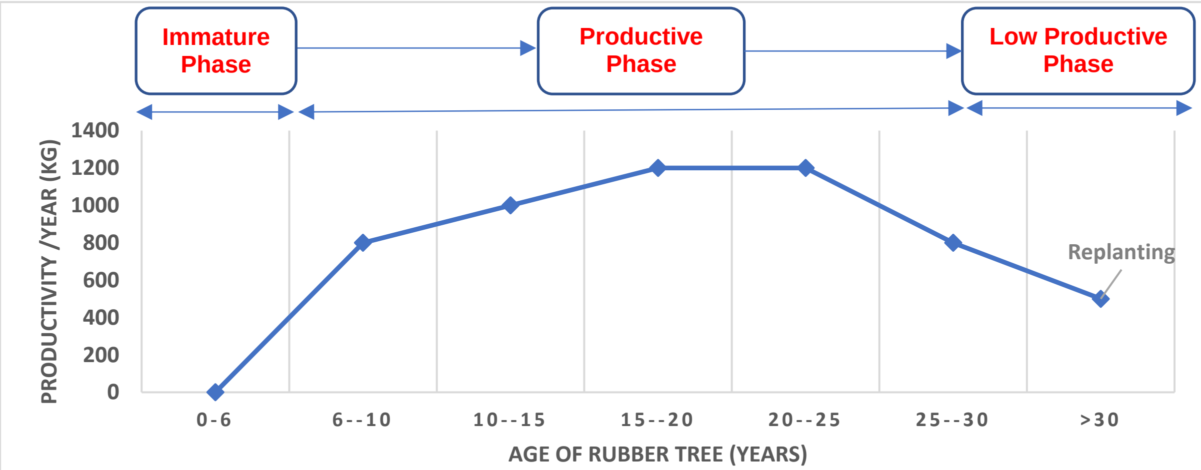

Figure 1.7 Life Cycle of Rubber Tree

Current planning practices for rubber replanting in Indonesia have nonetheless generally failed to consider the significance of replanting allocation and have not adequately considered sustainability impacts that might occur as a result of replanting. The current planning practice of Indonesian replanting policy in the natural rubber industry thus presents various opportunities for enhancement, particularly with regard to the use of sustainability aspects in the consideration of the formulation of replanting policies. This research focused on exploring ways to incorporate sustainability aspects in the formulation of replanting policies in order to improve the sustainability of natural rubber supplies from Indonesia's natural rubber supply network.

Three research questions were addressed:

- What are key requirements for the assessment of the sustainability of replanting policies in the Indonesian natural rubber industry supply network?
- What are necessary characteristics of an integrated assessment tool for use in the assessment of the sustainability of replanting policies?
- How might an integrated assessment tool be used to inform decisions related to the formulation of replanting policies in the Indonesian natural rubber industry supply network?

1.3.2 Aim and Objectives

The overarching aim of this research was to explore ways in which social, economic and environmental aspects of sustainability can be used to inform decisions related to the formulation of replanting policies in the Indonesian natural rubber industry supply network. The following objectives are pursued:

1. To identify current approaches for developing sustainable supply networks from literature and the Indonesian natural rubber industry.
2. To develop a case study of the Indonesian upstream natural rubber supply network, including the identification of key questions and issues for the formulation of sustainable replanting policies.
3. To identify requirements for the formulation of sustainable replanting policies in the Indonesian natural rubber industry supply network.
4. To design and prototype an approach for the formulation of sustainable replanting policies that takes into account practical constraints such as data availability, scope of area that will be covered, and performance criteria.
5. To verify the approach by using it with target users to formulate sustainable replanting policies in the North Sumatera natural rubber industry.

1.4 Thesis Outline

This thesis presents a new approach for formulating sustainable replanting policies in the Indonesian natural rubber industry supply network. Chapter 2 reports a literature review, which explored and assessed recent literature around sustainable supply networks, with a focus on approaches for using sustainability aspects to inform decision-making at the forward stage of supply networks in the agricultural industry. This chapter also identifies gaps in contemporary research that the present study addresses.

Chapter 3 outlines the research methodology and process. This chapter focuses on explaining research approaches and method as well as detailing each stage of the research process. Chapter 4 introduces a case study of the North Sumatera natural rubber industry. The analysis of North Sumatera’s industry covers its current problems and opportunities, as well as the structure of its supply network and the behaviour of stakeholders within the network. Included in this chapter is also the modelling of key players’ decisions in the upstream natural rubber supply network.

Chapter 5 presents the approach for formulating sustainable replanting policies. This chapter describes the process, gives sustainability indicators, and describes the strategic planning tool for the formulation of sustainable replanting policies. The chapter also presents verification and validation processes for the strategic planning tool. Chapter 6 focuses on the application of this approach for formulating sustainable replanting policies in the North Sumatera natural rubber industry. Finally, in chapter 7, the key findings in which the contribution to knowledge and directions for future research are discussed. Figure 1.8 illustrates the way that chapters relate to each other.

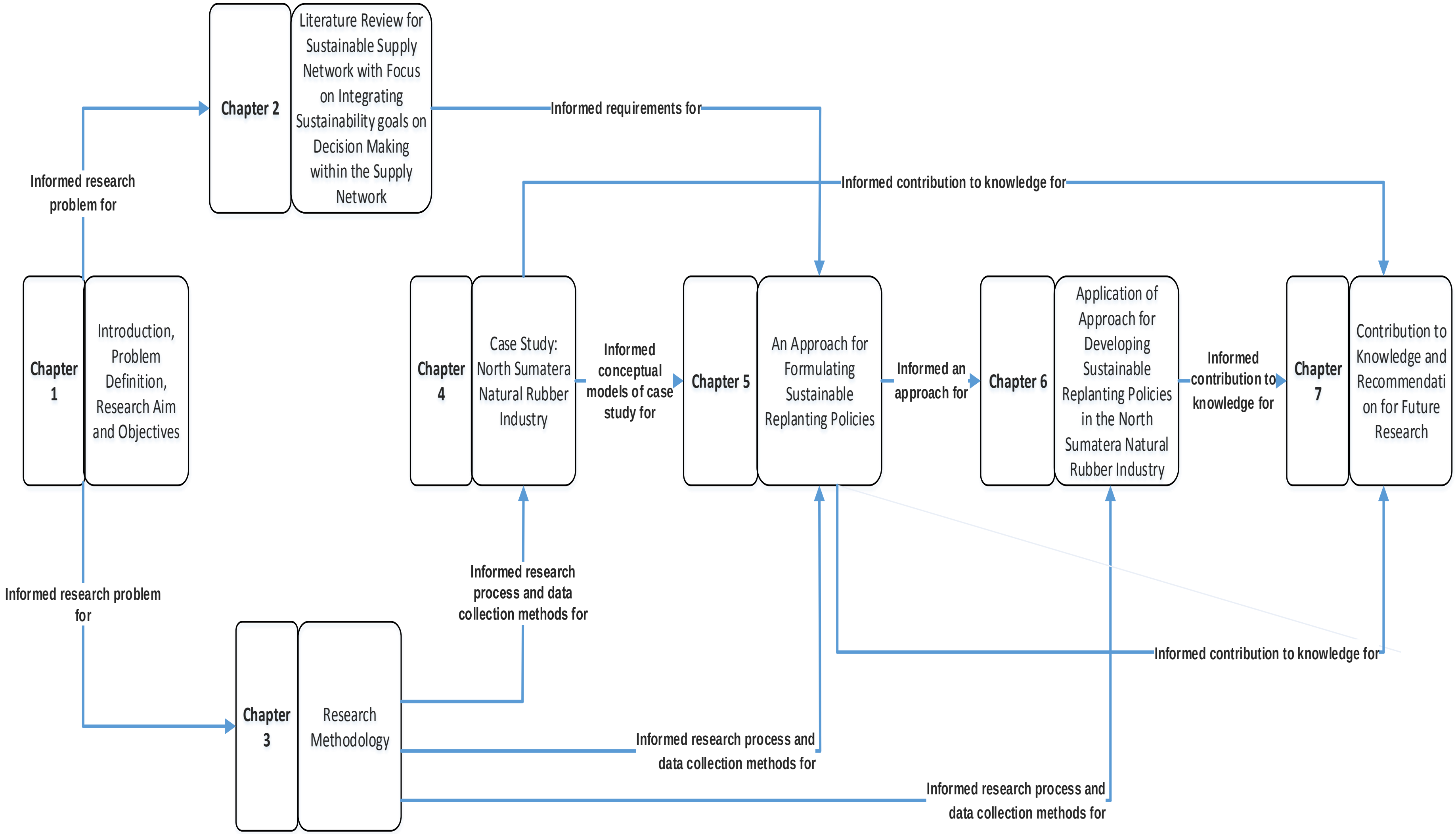

Figure 1.8 Chapter Relationship

Chapter 2
Literature Review

This chapter presents a review of approaches for developing sustainable supply networks. Analyses of literature aim to gauge an understanding of ways that sustainability aspects can be used to inform decision making within supply networks, and further aim to uncover and address gaps in contemporary research. The following review is expected to provide information in defining requirements for the formulation of sustainable replanting policies.

The text that follows is divided into five sections. The literature review is introduced in section 2.1 with definitions, concepts, and challenges around sustainability. This is followed by section 2.2, which introduces the concept of sustainable supply networks, an idea emerges from the integration of sustainability into supply networks. Following this, section 2.3 introduces an overview of sustainability assessments within the supply network. This section focuses on reviewing approaches for assessing sustainability in supply networks, with a particular focus on assessing rubber plantations and identifying influential factors in the selection of appropriate assessment methods for measuring sustainability. This theme is continued into section 2.4, which presents an overview of sourcing planning models in the supply network. This section focuses on reviewing approaches for planning optimum sourcing in upstream supply networks, with a particular focus on agricultural industry. The conclusion, findings, and gaps in extant literature are all summarized in section 2.5. Figure 2.1 illustrates the way that these sections relate to each other.

2.1 Sustainability

First, it is important to fully understand the concept of sustainability. It is an uncontested fact that environment provide natural resources that generally fulfil the demands of humanity. However, with an increasing global population, more pressure is brought to bear on the environment, not least owing to the vast extraction of these natural resources. This damages the environment, which in turn endangers human life, particularly with regard to human health and prosperity.

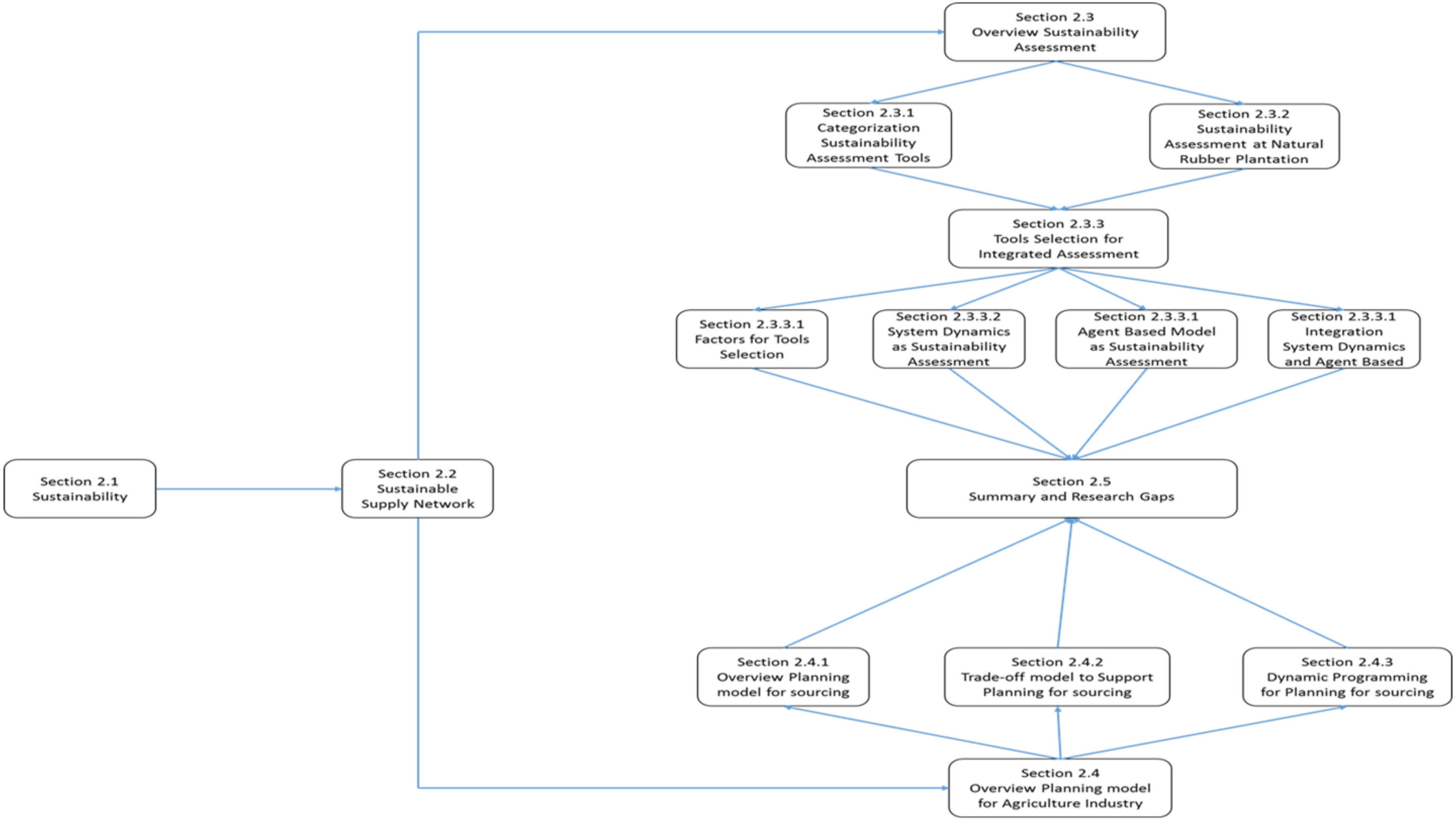

Figure 2.1 Relationship between Literature Review Sections

In the contemporary age, humans have started to recognize that the environment has a limited capacity for satisfying human needs and scholars have begun to revisit the relationship between humanity and environment (Meadows and de Rome, 1974). Sustainability emerged initially as a concept that emphasised the harmony between humans and environment, with particular importance assigned to human welfare and environment preservation (Epa and Office of the Assistant Administrator, 2012). The broadest and most quoted definition of sustainability is given by the World Commission on Environment and Development, who link sustainability with development, and subsequently established the idea of sustainable development. The latter is described as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”.

It is clear that the practical enaction of this definition requires a significant transformation in human systems of production and consumption, in order to preserve natural resources for our future generations. However, for many contemporary organizations, from government to business organizations and even non-profit organizations, this definition is all too vague, particularly when it is interwoven with the specific planning, operation and production practices of specific organizational cultures (Cochran et al., 2011).

To address this problem, Elkington (1999) proposes three pillars of sustainability, comprising economic, environmental and social aspects. This three-factor definition is widely known as the triple bottom-line concept. Elkington argues that corporations should focus on maintaining social and environmental value as well as economic value. In this way, measuring the environmental and social impact of corporate activities is just as important as measuring the economic value of corporate activities.

Currently, sustainability has become an essential issue for many industries and business organizations. This is owing to several factors motivating companies to adopt sustainability issues within their business strategies, processes, and activities, the cumulative impact of which is often described as a sustainability driver (Mann et al., 2010). A wide body of literature exists that focuses on reviewing sustainability drivers.

Seuring & Müller (2008b) identify specific triggers in business organizations that prompt them to become more sustainable. Triggers can come from the government, from consumers, and from other stakeholders, in the form of pressures and incentives. These pressures and incentives have been defined in recent research studies by Bowen et al. (2006), Rao & Holt (2005), Vasileiou & Morris (2006), Welford & Frost (2006), and Zhu & Sarkis (2004), who have divided sustainability triggers into six major areas: legal requirements/regulations, client demands, responses to stakeholders, competitive advantages, environmental and social group pressures, and reputation loss. Studies have also shown that companies can push other companies to be more sustainable owing to existing relationships and partnerships. This can be observed in supply networks where companies push their suppliers to follow their own company sustainability requirements.

In another study, Gopalakrishnan et al. (2012) identify six factors at work in sustainability drivers. The first factor relates to regulations around environmental and social impacts in processing and production. These regulations emerge at a regional and international level. For example, REACH (Registration, Evaluation and Authorization of Chemicals) and Environmental Liability are both regulations encompassed by the European Union, which force companies to maintain their operations at minimal environmental impact. At the international level, the United Nations have succeeded in launching two notable agreements regarding corporate sustainability: the UN Framework Convention on Climate Change and the Kyoto Protocol. Both of these agreements have been ratified by many countries that subsequently participate voluntarily in the reduction of their territories' emissions.

The second factor identified by Gopalakrishnan et al. is stakeholder pressure. Employees, customers, socially aware organizations and communities all comprise stakeholders that can actively push the integration of sustainability within corporate practice. The environmental and social sustainability of any organization can be positively influenced by employees and by middle management (Alt et al., 2015; Carter et al., 1998; Hanna et al., 2000). Corporations generally require the active involvement of management in order to achieve specific visions and missions corporation (New and others, 2000; Wycherley, 1999). The active involvement of management can also be achieved by maintaining employee satisfaction. Customers, too, can occupy a substantial role in pushing the integration of sustainability into corporate agendas (Dagher and Itani, 2014). Walker et al (2008) find that the sensitivity of organizations to customer pressure is often influenced by the size of organization. Moreover, a company with a good reputation or image is often more sensitive to customer pressure. Reputational damage is often a real and detrimental result of companies failing to pursue eco-friendly practices.

The third factor given by Gopalakrishnan et al. is the depletion of resources. The mass consumption of natural resources is a main contributing factor in resource depletion. Unfortunately, this factor, though fundamental in itself, is not generally located as a main sustainability driver in organizational practice, unless the reduction of natural resources contributes to a decline in the economic performance of a given organisation. Natural resource depletion can be slowed by the integration of sustainability methods, since the latter requires innovations that improve material efficiency, energy efficiency, and also recycle end-of-life products. Furthermore, it has been found that these activities contribute to cost reduction for many organisations (Hami et al., 2015).

The fourth factor in Gopalakrishnan et al.'s list is a low carbon economy. The reduction of carbon emissions per capita comprises the main objective of low carbon economic practice. According to Das Gandhi et al (2006), among many others, global warming is predominantly caused by carbon emissions. Many companies have been subsequently pressured to reduce their carbon emissions, the latter being generally emitted from company operations and supply chains. Integrating sustainability is one obvious way to reduce carbon emissions. Carbon taxes and carbon trading are two examples of sustainability practices that can be effective carbon reduction. Indeed, these practices have been implemented by many countries and recognized as successful, cost-effective mechanisms for sustainable development (Labatt and White, 2011).

The fifth factor provided relates to environmental standards. The emergence of environmental standards such as life cycle assessments, carbon disclosure projects, environmental auditing, and sustainability reporting have all contributed to increasing environmental awareness within the operations of supply chains. These measurement methods underpin the ability of companies to evaluate environmental impact and implement sustainable practices. Further to this, the International Organization for Standardization have introduced ISO 14001, which can be applied by companies to reduce risks associated with the environmental impact of commercial activities (Miles et al., 1999).

The sixth factor relates to social responsibility. Companies have an obligation to people working within their businesses – their employees – as well as to those outside their businesses – the wider community. This obligation is vital for the maintenance of social wellbeing among the people surrounding business activities. The implementation of sustainability practices can improve social wellbeing. (Graafland& Mazereeuw-Van der Duijn Schouten, 2012). For example, Ciliberti et al. (2008) show that companies with a higher level social responsibility find it easier to adopt sustainability practices. Furthermore, the emergences of social standards such as the Social Accountability (SA) 8000 and ISO 26000 have contributed to companies being better able to formulate activities with a higher social value.

The integration of sustainability within the triple bottom-line model of business activities and processes requires several strategies. These include the measurement of economic, social, and environmental impacts and the analysis of trade-offs between economic, social, and environmental dimensions, so as to make better decisions at a strategic, tactical, or operational level. Firstly, the measurement of economic, social, and environmental impacts from business activities is crucial. Gauging these impacts is an important part of measuring the sustainability of activities and processes carried out by any given individual, organization, business or government (Singh et al., 2009). Furthermore, information related to economic, social, and environmental impacts are essential for the construction of strategic, tactical, and operational business, leading, in turn, to more sustainable business practices overall (Rotmans, 2006).

The second strategy for the integration of sustainability with triple bottom-line practices comprises a considered trade-off between economic, social and environmental goals. This trade-off is important for ensuring that the three pillars are engaged with at every juncture of business decision-making (Carter and Rogers, 2008). Indeed, specific decisions may have opposite impacts. For example, not all environmental practices will be cost efficient, and some of these practices will even increase costs, as a result of proactive investment in green technology. Margolis et al. (2007) analyse several companies that have taken corporate social action, noting that some of these actions affected organizations' financial health. Nevertheless, this fact does not require increased attention on the adverse effects of environmental and social dimensions upon economic performance (Winter and Knemeyer, 2013). Organizations can still participate actively in environmental and social activities since the latter not only positively affect the natural environment and society, but companies will also benefit from the increased competitiveness and long-term socio-economic rewards.

2.2 Sustainable Supply Networks

This section introduces the concept of sustainable supply networks to contemporary mainstream research in the field. Since the main aim of sustainable development is to ensure the maintenance of current and future generations, supply networks occupy an important role in delivering products or services that can satisfy human demand. Nonetheless, several activities within supply networks have been found to be a source of pollutants that in fact reduce the quality of human life and the environment (Zailani et al., 2012). Manufacturing and transportation, for example, comprise two of the main activities in a supply network that both contribute to increase emissions and waste across network levels. The concept of sustainability is therefore provided as one solution for the minimization of adverse effects within the network.

Supply networks can be defined as network of organizations and companies that focus on generating value in the form of products and services for other organizations or companies within a given network (Lysons and Farrington, 2006). According to Kito and Ueda, (2014), supply networks can be described as a set of nodes and links. Nodes represent organizations, and links represent supply relationships and other types of relationship, such as human resources and financial connections. Thus, supply networks are formed by two or more organizations, which are in turn connected by material flows, themselves with information and financial flows occurring between them. Organizations can encompass numerous types of business, from producer, manufacturer, and processor, to distributor, retailer and wholesaler. Ultimate consumers are also relevant, and can be considered an important organization within any supply network (Safaei et al., 2014).

The emergence of sustainable supply networks as a concept has prompted some academics to further determine definitions and to actualize sustainability within supply network practices. Seuring & Müller (2008) define sustainable supply chain management as the “management of material, information, and capital flows, as well as cooperation among companies along the supply chain, while integrating goals from all three dimensions of sustainable development, i.e. economic, environmental and social, which are derived from customer and stakeholder requirements”. Similarly, Carter & Rogers (2008) describe sustainable supply chains as the strategic and transparent integration and achievement of an organization’s social, environmental, and economic goals in the systemic coordination of key inter-organizational business processes, for the improvement of an individual company’s long-term economic performance, as well as the performance of its supply chains. The most recent definition, given by Ahi & Searcy (2013), defines sustainable supply chain management as involving the integration of corporate sustainability, whereby key dimensions of corporate sustainability are combined with the characteristics of a supply chain.

The actualization of sustainable supply networks has been explored by numerous scholars, who have variously investigated the different stages of supply networks for different types of industry. These studies have resulted in some important innovations and approaches for the enhancement of supply network sustainability. To map these innovations, researchers have proposed a wide range of frameworks (Seuring and Müller, 2008b; Carter and Rogers, 2008a; Hassini et al., 2012a; Turker and Altuntas, 2014). The conceptual framework presented by Seuring and Müller (2008) is the outcome of a comprehensive review of 191 articles relating to sustainable supply chain management. The authors identify three major areas that subsequently become the main focus of research: triggers for sustainable supply chains, supplier management of risks and performance, and supply chain management for sustainable production. Regarding supplier management for risk and performance, recent research identifies risks and disruption opportunities attendant upon environmental and social performance. Further assessments are therefore required for the investigation of activities' impacts on supply networks, not only with regard to economic performance but also to environmental and social performances, for the avoidance of risk. Supply chain management for sustainable production requires the creation of sustainable products by improving production processes. Innovations in this area have delivered models such as the product sustainability index and life cycle assessment that both allow for the assessment of product and process sustainability.

Carter and Rogers (2008) present a conceptual framework that is based on the triple bottom-line concept and is focused on solving conflicts around objectives in sustainable production. The authors divide sustainable activities into four intersections: the intersection between economic and environmental factors; the intersection between economic and social factors; the intersection between environmental and social factors; and, finally, the intersection between all three dimensions, economic, environmental, and social. An intersection between two dimensions is described as preferable, while an intersection between all three dimensions is provided as optimum. The authors find that most recent research focuses on improving only one or two sustainable dimensions. There are few examples of research that has engaged with all three dimensions simultaneously. Furthermore, Carter and Rogers find that improving one dimension of sustainability has a potentially adverse effect on other sustainability factors.

An alternative conceptual framework is offered by Hassini et al. (2012a). The authors here focus on investigating recent innovations across different stages of supply networks. In order to do this, they develop a framework that is visualised as a wheel with six spokes. Each spoke represents a major stage across the supply chain. These six stages comprise: sourcing, transformation, delivery, customer, value proposition, and recycling. The sourcing stage encompasses the use of renewable resources, conducting fair trade practices, preventing damage to environment, and limiting the generation of toxic substances and Green House Gas (GHG) emissions. In the agricultural industry, this sourcing stage occupies a critical position. Tsolakis et al. (2014) have argued that decisions around optimal sourcing comprise a critical component in agricultural supply networks. Recent research around the transformation stage generally focuses on sustainable practices and fair labour practices. At the delivery stage, research has tended to focus on transportation, facility location and layout, inventory, and greenhouse gas emission. Contemporary research around the customer stage is mostly engaged with energy efficiency, the use of green energy, customer education, and GHG emission. Value proposition is given as the additional cost taken on by customers, as a subsequent effect of additional costs incurred by environmental action taken by companies. Research around this stage generally investigates the willingness of customers to pay for this additional cost. Finally, at the recycling stage, recent research has mainly focused on decision-making around allocating end-of-life products, and their destinations as either returned, reused or recycled materials.

Another recent conceptual framework has been outlined by Turker and Altuntas (2014). This framework functions as an extension of Seuring's framework, and has been implemented to analyse sustainability in the fast fashion industry. Turker and Altuntas' paper suggests that the implementation of sustainable supply chains vary across each industry depending on the structure of supply networks and each industry's sustainability requirements.

It can thus be concluded from recent innovations in the field of sustainable supply networks that the latter require sustainability drivers that function as pressures and incentives on organizations to be more sustainable (Seuring and Müller, 2008b; Gopalakrishnan et al., 2012). The integration of sustainability into supply networks require the assessment of existing sustainability mechanisms within specific supply networks (Seuring and Müller, 2008b; Hassini et al., 2012b). Assessments of this sort will impact activities within supply networks across all three dimensions of sustainability. To maintain results, certain trade-offs are required in the planning of future activities across networks, which will in turn ensure that the three dimensions of sustainability are ascertained. Flexible approaches to improving sustainability may be required for application within different industries (Turker and Altuntas, 2014) and at different stages of supply network (Hassini et al., 2012b).

The effective integration of sustainability into supply networks creates new challenges through further complicating the way we assess sustainability, and by emphasising the trade-off between sustainability goals. When networks are taken into account in the assessment of sustainability, the impact of policies, activities, and processes of all organizations within the network require consideration. The impact of policies may differ for individual organizations across the network. For example, in the natural rubber supply network, the impact of rubber replanting policies may be different for rubber smallholders – replanting removes income from rubber plantations owing to immature growing phases, and for suppliers and primary processors, replanting reduces the material flow within networks. As a result, the assessment of supply networks should reflect the cumulative impacts of all activities of organizations within the network, rather than impacts generated by one organization only. To address this issue, further investigation is required for integrating networks within sustainability assessments.

Similar circumstances occur when we consider network trade-offs between sustainability goals. As supply networks consist of different types of organizations which have different perspectives around sustainability and different sustainability goals, trade-off processes are no longer just between sustainability goals, but also between the objectives of several key players within the network. For example, in the upstream natural rubber supply network, key players may have different objectives. Rubber smallholders and steppers will want to sustain income from rubber plantations, while suppliers want to sustain the flow of materials. Moreover, the government wants to minimize the environmental impact and to sustain income from natural rubber industries, while primary processors want to have a stable supply of natural rubber for production.

2.3 Overview of Sustainability Assessment

This section presents recent methods and tools for assessing sustainability in supply networks. To deliver this, three sub-sections are introduced. Sub-section 2.3.1 analyse the advantages and disadvantages of recent tools and methods for assessing sustainability. In sub section 2.3.2, the focus is narrowed to an investigation of recent sustainability assessments at the rubber plantation stage. Following this, in sub section 2.3.3, a discussion is introduced around the factors influencing methods of sustainability assessment.

Exploring sustainability and sustainable supply networks illustrates the importance of assessing sustainability in supply networks. Despite significant economic impact, several activities within networks, such as manufacturing and transportation, contribute to increasing pollution, in turn reducing the quality and health of the environment. Several social benefits can also be identified within supply networks, from heightened community welfare to increased social well-being. Researchers have subsequently started to investigate the impacts of activities on three dimensions of sustainability across different sectors. An assessment tool to assess sustainability has in turn emerged in order to address this problem (Hoogmartens et al., 2014).

Devuyst and Hens (2001) define a sustainability assessment as “a tool that can help decision-makers and policy-makers decide which actions they should or should not take in an attempt to make society more sustainable”. Ness et al. (2007) elaborate on this, by adding a spatial aspect and a time horizon into their definition, describing a sustainability assessment as “an evaluation of global to local integrated nature–society systems in short and long term perspectives, in order to assist them to determine which actions should or should not be taken in an attempt to make society sustainable”.

According to Sala et al (2015), a sustainability assessment consists of three important dimensions, including the approach to sustainability, decision context, and methodology context. The approach to sustainability refers to viewpoints held by creators and users of sustainability assessments. Sala et al. (2015) incorporate this dimension into the value of sustainability principles, while Pope et al. (2017) categorize as an underpinning component of sustainability discourse and representation. Stakeholders within the system may have different perceptions of sustainability. Some may be strong proponents of sustainability, who wish to limit natural capital extraction. Others may wish to maintain the total stock of capital by allowing for capital substitution. All of these perceptions will influence the assessment process.

The second dimension in a sustainability assessment refers to the decision context. Pope et al. (2017) divide this dimension into three sub-topics, including the subject of assessment, the decision question, and the responsible party while Sala et al (2015) emphasise the object of assessment, the factors influencing decisions, and approaches to the decision. The subject of assessment refers to policies, products, processes, or institutions that all become targets requiring assessment. Pope et al. (2017) link the subject of assessment with decisions that will be supported by assessment, while Sala et al. (2015) focus on factors influencing decisions, including actors, scales of assessment, the complexity of decisions, the uncertainty of decisions, the time horizon, the activity affected by the decision, and impacts of interest. Sala et al. (2015) categorise approaches to decision into scenario-oriented or target-oriented approaches. Contrastingly, Pope et al. (2017) emphasise the importance of the users who will run the assessment process. The authors specify this as the regulators involved in external assessment, external third parties, and proponents within internal assessment.

The third dimension delineated comprises methodologies of assessment. Sala et al. (2015) define methodologies as collections of individual methods for analysing impacts of assessment across economic, environmental, and social dimensions. Methodologies comprise the core of sustainability assessment. According to Lee (2006), methodologies consist of both process and method. Process refers to the identification of a set of steps for performing assessments, and method refers to the identification of a set of tools to be used as analytical techniques that are applied within the assessment process. Sala et al (2015) add a selection of indicators that gauge sensitivity and uncertainty within methodologies.

2.3.1 Categorization of Sustainability Assessment Tools

The main purpose of sustainability assessments is to support decision-making processes inside the system. Decision-making at this level is conducted to decide whether plans, product, processes and activities that run in an integrated nature-society system can contribute society's overall sustainability. However, owing to different plans, products, processes, and activities in different systems, researchers and academics propose a variety of different approaches to assess sustainability within different sectors and field. Subsequently, sustainability assessment models have proliferated into a diverse range of forms purpose-built for different sectors and fields (Pope et al., 2017).

Ness et al. (2006) and Gasparatos and Scolobig (2012) attempt to categorise recent sustainability assessment tools available in the literature. Ness et al. (2006) consider three factors in the categorisation of sustainability assessment tools, including temporal characteristics, the focus of assessments, and the sustainability dimensions covered, while Gasparatos and Scolobig (2012) consider valuation perspectives, the adoption of a reductionist perspective, and the acceptability of trade-offs between sustainability issues. Ness et al (2006) categorize sustainability assessments into three main groups, including indicators and indices, product related assessments, and integrated sustainability assessments, while Gasparatos and Scolobig (2012) categorize assessments into three main groups, including monetary tools, biophysical tools, and indicator tools.

Ness' framework has been adopted to evaluate recent sustainable assessment models in contemporary literature. The first group in Ness' framework comprises indicators and indices. An indicator is given as a value that describes the economic, social, and environmental condition of certain regions. If the value of the indicator is aggregated, then it is called an index. The main benefit of indicators is in their ability to summarise, focus, and compress intricate situations of our dynamic economic, environmental, and social world into one meaningful value (Singh et al., 2012). However, indicators are also applied to evaluate past development and are unable to predict future outcomes (Ness et al., 2006).

According to Ness et al. (2006), indicators can be divided into three categories, including integrated indicators, non-integrated indicators, and regional flow indicators. Integrated indicators refer to the index that is aggregated from several indicators. An example of integrated indicators can be found in national accounting, e.g. gross domestic product and net national product. Non-integrated indicators refer to a single indicator that is not aggregated. Environmental pressure indicators and the United Nations commission on sustainable development examples of non-integrated indicators. Regional flow indicators refer to the value for a total of materials or energy that is calculated from the materials and energy used within a given system, e.g. indicators for material flow analysis and substance flow analysis.

Currently, indicators have been initiated by institution. For example, the United Nations has proposed the sustainable development indicators; the South Pacific Applied Geoscience Commission has launched the Environmental Vulnerability Index; and the University of Yale has announced the Environmental Sustainability Index. These indicators have all been implemented at national level. Current challenges for indicators are to define global indicators, Individual indicators, and to capture the dynamic changes of systems (Dahl, 2012). To address this, some researchers such as Hassini et al. (2012b) and Singh et al. (2012) have proposed composite indicators. This method is used to aggregate some indicators into the index. This process is necessary while various indicators emerge for different sectors and fields. One example of a composite indicator is the Product Sustainability Index (Shuaib et al., 2014).

The second group in Ness' framework is a product-process related assessment. Life cycle assessment (LCA) comprises a sustainability assessment tool that is widely accepted for product-process related assessments. The main idea behind life cycle assessments is the demarcation of impacts of products across their life cycle, starting from raw material, production, and distribution until consumption. The popularity of this tool has increased significantly, as process productions leave an environmental footprint, which has prompted the standardisation process of this tool into ISO 14000. According to Fiksel (2010), life cycle assessment (LCA) is a collection of methodologies that investigate the implications of processes, products, and services in the environment, by using a life cycle perspective. To address the three elements of sustainability, LCA has been improved by academics and researchers. This has rendered two types of LCA: economic LCA and social LCA.

Social sustainability has been generally addressed by social LCA. Social LCA can furthermore be differentiated from corporate social responsibility (Hoogmartens et al., 2014). Following social LCA, economic dimension have been targeted to predict costs occurred within the product life cycle. This tool is known as life cycle costing (LCC). This assessment compares the durability of products with their purchasing price. Additionally, the tool provides for the cost incurred within the life cycle of the product, where purchasing price is discounted into current value (Klöpffer and Ciroth, 2011).

Other approaches for analysing materials and energy that are used within production processes are material flow analysis and product energy analysis. Material flow analysis focuses on calculating materials related to products, while product energy analysis focuses on investigating the total energy resulting from production. Some researchers have developed a model to support this assessment, such as material input per unit service (Ness et al., 2006) and material, energy, waste process flow modelling (Smith and Ball, 2012). As all tools in this group focus on assessing products or processes, the spatial dimension has been somewhat neglected in the assessment process. Moreover, most of the tools in this group are applied to assess one specific dimension, either environmental, economic, or social (Ness et al., 2006).

The last tool in Ness' framework is an integrated sustainability assessment. Rotmans (2006) defines integrated sustainability assessments as "the science that deals with an integrated systems approach to complex societal problems embedded in a process-based context**".** The main aim of integrated sustainability assessments is therefore to create a strategic solution for a complex problem by developing policy options, which are subsequently defined from an impact analysis of multiple causes. This type of tool has been developed to address the limitations of previous sustainability assessment tools for specific development policies or plans in certain sectors or industries. Increasingly complex systems and the multidimensional nature of sustainable development render new approaches necessary for sustainability assessments. The flexibility of integrated assessments for combining different analytical models has become the main advantage of this approach, particularly in its ability to assess specific policies, something that requires the factoring of spatial dimensions as well as a focus on long-term sustainability.

Ness et al (2006) divides integrated sustainability assessments into six categories, incorporating: conceptual models and system dynamics, multi criteria analysis, risk analysis, vulnerability analysis, cost and benefit analysis, and impact assessment. In contrast, De Ridder et al. (2007) group integrated sustainability assessments into seven categories: assessment frameworks, participatory tools, scenario analysis tools, multi criteria analysis tools, cost-benefit analysis, accounting tools and physical analysis tools, and model tools. Some of these tools are already established within the field, and have been implemented not only in the areas of sustainability but also in other problems areas (Ness et al., 2006).

Integrated sustainability assessments have been widely used in across sectors. For example, multi criteria analyses have been used by Džiugait et al. (2017) to construct an alternative solution to rising energy demand within energy supply systems. This assessment uses four criteria, comprising: energy efficiency, environmental impact, economic impact, and technical functionality. In the agricultural sector, Gandolfi et al. (2014) introduces an integrated assessment framework consisting of an economic model that predicts changes in land use, a spatially distributed hydrological model to assess water requirements, and an optimisation model. This integrated model has been used to connect agricultural policy with water resources planning. Another approach to integrated sustainability assessments is presented in the works of Chardine-Baumann and Botta-Genoulaz, (2011). The authors propose an analytical model to assess the impact of sustainable development, that ascertains three dimensions of sustainability, whereby each dimension into divided into fields and sub fields. The fundamental steps in this model are the connection of sustainable development with fields and subfields, and the subsequent evaluation of its impact. Engaging with contemporary literature can therefore elaborate on the relationship between sustainability practices and its fields and subfields, as well as evaluate the impact of sustainable development on industry practices.

Indicators and indices are able to evaluate past developments that have been implemented. This sustainability assessment method is usually used at a national level, although indicators for individual products – e.g. the product sustainability index – expand insights significantly owing to the availability of composite indicator methods. Using composite indicators, the focus of assessments can be designed to ascertain all three sustainability dimensions.

Product-related assessments are capable of evaluating several activities related to a product’s life cycle. This assessment method works well for the analysis of impact for each stage of product development. Still, this assessment method must be supported by measurement data. Furthermore, this type of assessment neglects spatial dimensions and other criteria for the evaluation of past and current activities. Indeed, the focus of product-related assessments generally comprises only one dimension of sustainability.

Integrated sustainability assessments are well suited to the evaluation of plans, projects, and policies. The scope of these assessments can be designed for local, regional, national, and global levels. The main advantage of integrated sustainability assessments is their ability to predict long-term sustainability impacts. This type of assessment has the flexibility to illustrate the complexity of systems as well as the overall dimensions of a system's sustainability.

Integrated supply networks in sustainability assessments have the potential to improve the complexity of assessment processes. As such, the integrated sustainability assessment method offers an opportunity to address this issue by having the ability to detail the workings of complex systems. This is generally owing to the flexibility of integrated sustainability assessments in their capacity to combine different approaches and methods for assessing sustainability. The combination of different approaches improves the ability of assessment methods to capture the nature of complex supply networks, as well as widening the scope of assessment. Despite the superiority of integrated sustainability assessments, the implementation of this method to assess sustainability in supply networks is not particularly widespread in contemporary literature.

2.3.2 Sustainability Assessment in the Rubber Plantation Stage

This section introduces recent methods that have been used to assess sustainability at the stage of rubber plantation. In the natural rubber supply network, the plantation stage supplies raw material for the next stages, including to the primary processor and to the downstream industry. As such, improving sustainability at this stage will have a positive impact on the primary processor and the downstream industry.

- **Economic Assessment**

The raw material in rubber plantations comes from a renewable source, the rubber tree (*Hevea Brasiliensis*). In order to sustain natural rubber supply, rubber trees must be available. However, the rubber tree has a life cycle that consists of three phases: the immature phase, productive phase, and low-productive phase. In the immature phase, the rubber tree has zero productivity – this means that, during this stage, it does not produce rubber. Rubber trees instead generally become productive after six years.

The characteristics of rubber tree life cycles have prompted researchers to investigate the economic dimensions of plantations. These dimensions matter, because different costs are incurred at every phase of rubber trees' life cycles. At earlier phases, for example, cost are incurred for land clearing, seeding, and planting which increases this phase’s expense compared with other phases. Guo et al. (2006) investigate the profitability of rubber plantations during a single cycle or rotation. The authors implement the Land Expectation Value method to calculate the economic impact of rubber plantation. They furthermore compare the profitability of rubber plantations with tea plantations, as well as evaluating the profitability of intercropping plantations (rubber and tea). A similar approach is implemented by Yi et al. (2014). In the latter, the authors illustrate the economic impact of rubber plantations at different sites. Using a spatial model of rubber plantation, rubber yield from different sites was predicted. This was subsequently used to calculate the net present value of each site. The researchers found that some sites had a negative NPV value. However, the profitability of a given plantation is influenced by the productivity of a plantation.

Many factors influence the productivity of plantations. Siagian and Siregar (2013) identify factors influencing this productivity, including the density of trees, the total of tapping per year, and the productivity of trees. The density of trees comprises total number of rubber trees per hectare area. Optimal plantations should generally have 450-600 trees per hectare. Decreases in plantation density may be caused many trees having died because of plant disease and wind. As a result, production is diminished owing to a paucity of tress that can produce the material for latex (Sibagariang et al., 2013). To address this issue, Siagian and Siregar (2013) propose a double planting system that will increase the total number of rubber trees planted at first planting.

Total figure of tapping per year comprises the frequency of tapping that has been implemented for one rubber tree per year. The implementation of a non-standard tapping system has had the effect of reducing productivity, owing to broken layers of rubber tree (Purwaningrum et al., 2016). Chantuma et al. (2011) compare different tapping systems to define the best tapping strategy for each phase in a rubber tree’s life cycle. The authors find that the double-cut alternative tapping system gains a higher yield in the first nine years of tapping, compared to two other recommended tapping systems.

The productivity of a given rubber tree is influenced by many factors, from the type of clone to the implementation of fertilizer, and the weather. The type of clones used has been proven to influence the productivity of rubber trees (de Souza Gonçalves et al., 2011). Afrizon & Ishak investigate the impact on productivity of using different clones in Bengkulu. Wijaya et al. (2014) has also investigated the impact of fertilizer on the productivity of rubber tree.

The second economic aspect investigated relates to smallholder income. Many rubber smallholders' livelihoods depend on income from rubber plantations. Devi (2015) investigates the impact of productivity on rubber smallholder income, which subsequently impacts the welfare of smallholder. Devi found that low productivity of plantations triggers a reduction in smallholder welfare. Furthermore, Candra et al., (2008) found that low incomes among smallholders result from low plantation productivity and also tend to influence decisions taken by smallholders to replant their land.

Rubber plantation has an additional financial impact for smallholders. Shigematsu et al. (2010) investigate the economic impact of wood production as a by-product from rubber plantation. The economic impact of wood is calculated using the land expectation value. The authors found that wood production can improve the profitability of a plantation. Furthermore, the value of harvesting wood at the end phase of plantation is sufficient to cover costs arising from re-establishment or replanting.

- **Environmental Dimension**

It becomes pertinent to investigate the environmental dimensions of the rubber plantation industry, as its numerous detrimental impacts, from loss of biodiversity to deforestation, are uncovered. The rising profitability of rubber plantations has led to massive land transformation around rubber plantations in Indonesia, Thailand, and China. These transformations have often sadly occurred in protected areas such as forests and conservation areas, triggering deforestation and biodiversity loss (Ahrends et al., 2015). To address this problem, researchers have developed a model to assess the impact of rubber plantation expansion. Yi et al. (2014) offer a predictive equation for species diversity in order to calculate the biodiversity loss attendant upon rubber plantations, and Villamor et al. (2014) have developed an agent-based model to ascertain biodiversity in rubber agroforests. Some researchers have focused their research on investigating the impact on specific species. For example, Phommexay et al. (2011) investigate the impact of expanded rubber plantations on bat population, and Zheng et al. (2015) investigate the spider population in rubber plantations.

Still, rubber plantations do also generate some positive affects for the environment, as they absorb carbon emissions and become carbon stocks. Numerous researchers have created a comprehensive picture of the way that rubber plantations are able to absorb carbon and act as carbon stocks. In Brazil, Wauters et al. (2008) examine the ability of rubber plantations in Brazil and Ghana to act as a carbon sink. Using allometric relationships, the researchers find that carbon stocks at rubber plantations in Ghana are higher than those at rubber plantations in Brazil. They also found that the age of rubber trees significantly influenced the ability of rubber plantations to act as a carbon sink. In Thailand, Petsri et al. (2013) estimate the carbon stock in Thailand using a logistical growth model. An important finding from their research points to an increasing trend of carbon stocks in plantations, occurring from the initial growth stage until the rubber tree reaches an age of 23-24 years. In Indonesia, Lusiana et al. (2014) determine carbon emission maps by detecting fluctuations of carbon stock from the year 2000-2009 in the Tanjabar Area. Furthermore, Supriadi, (2012) and Haryati et al. (2015) investigate the carbon stock level in smallholders' rubber plantations and determine factors influencing the carbon stock in smallholder plantations. Most recent research carried out by Blagodatsky et al. (2016) summarises carbon stock assessments from different countries and shows a level of uncertainty in carbon stock estimation, as well as in identifying factors influencing the carbon stock, from length of rotation and rubber clones to tapping frequency and planting density.

Rubber plantations produce emissions as a side effect of latex production and plant cultivation. These emissions have been investigated and compared with rubber plantations' abilities to absorb carbon. Jawjit et al. (2010) find that greenhouse gas emission in rubber plantations are mainly generated through the use of energy and fertilizer. The authors calculate greenhouse gas emissions for each activity in rubber plantations, using the functions of activities and emission factors. Their work is continued by Petsri et al. (2013) who calculate rubber plantation emissions between the years 1990 to 2004. The authors here extend the list of assessed activities by including burning that occurs during land preparation and the use of herbicide. The researchers subsequently find that more than 85% of emissions from rubber plantations occur through the implementation of fertilizer and herbicide.

Current approaches to assessing the environmental impact of rubber plantations have focused on greenhouse gas emissions, although other chemicals emissions have also been found in rubber plantations. To address this, Musikavong and Gheewala (2017) use a life-cycle assessment method to identify substances that emerge within the life cycle of a rubber plantation. The authors use data from life cycle inventories to create an ecological footprint assessment. The ecological footprint is found to vary between different locations in Thailand owing to various levels of water consumption and uses of fertilizer.

The process of environmental assessment needs to be supported by various information relating to the type of rubber clone, the age distribution of rubber trees, and the altitude of plantation areas. This type of information can be provided using an accurate map of rubber plantations. Some researchers have focused on creating innovative approaches for mapping rubber plantations. For example, Dong et al., (2013) propose the integration of PALSAR and the multi-temporal Landsat imaginary to create an accurate map of rubber plantation. Furthermore, Dibs et al. (2017) focus on improving the clarity of age distribution in the rubber plantation mapping system.

- **Social Dimension**

The presence of rubber plantations in many areas is often because of an intention to improve the welfare and livelihood of citizens in those areas. Rubber plantations produce raw material for several products such as tyres, hoses, gloves, and gaskets that all push up the price of rubber as a commodity. This attracts many governments to using rubber plantations as a route for improving the social welfare of their citizens. In fact, many types of research show that rubber plantations have succeeded in pushing economic growth.

To assess the social impact of rubber plantations, researchers have proposed many indicators and approaches. Wu et al. (2001) use several indicators such as local gross production, expansion of infrastructure, land conversion, and impact on indigenous people to observe the effects of rubber plantation expansion in Xishuangbanna. The authors find that rubber plantations increase local gross production by 27% and increase the availability of infrastructure including roads, power lines and water treatment. Rubber plantations have been cited as a cause of local people leaving traditional agriculture, and indigenous people leaving their original locations. A similar approach is conducted by Liu et al. (2006) and Fu et al. (2009). Zhang et al. (2015) also assess the impact of the different policies implemented by Xishuangbanna’s government in their drive towards rubber plantation expansion.

An alternative approach to assessing social impact has been conducted by Nath et al. (2013). The researchers here use a sustainable livelihood framework to assess the impact of rubber plantations in Bangladesh, India, and Sri Lanka. This framework shows the relationship between income generated by rubber plantations and the availability of physical assets such as land, equipment, and tools, and non-physical asset such as education and financial welfare. The authors find that rubber plantations have succeeded in improving the livelihood of citizens in Sri Lanka and India, while in Bangladesh, rubber plantations have proven to have had little impact. This is owing to the substantial income that can be gained from rubber plantations in Sri Lanka and India, while in Bangladesh, low incomes from rubber plantations were yielded. Furthermore, the authors find that good support from the government in terms of funding for maintaining plantations and institutional support has become essential in creating optimum plantation conditions.

However, current decline in rubber prices has had a significant socioeconomic impact on rubber smallholders. Firstly, rubber plantations are no longer profitable owing to cultivating costs being higher than production yields. Syarifa et al. (2016) investigate the impact of decreasing rubber prices. They find that falling rubber prices has the effect of decreasing the income of smallholders and the purchasing power of smallholders. Furthermore, declining prices has multiple impacts, including the reduction of rubber seed demand due to the low replanting rates, and the increasing desire of smallholders to look for alternative sources of income since rubber plantations are no longer profitable.

The focus of current assessments at the rubber plantation stage is generally to determine the impact of rubber plantation expansion on singular dimensions of sustainability. In terms of economic impact, current research focuses on assessing the profitability of plantations, using different approaches such as land expectation value and discounted cash flow. Another current research trend, concerning economic impact, focuses on identifying factors influencing rubber plantation productivity. Where the environmental impact is concerned, current research focuses on assessing biodiversity loss, greenhouse gas emissions, and carbon stocks as collective impacts of rubber plantation expansion. This environmental assessment is a response to the trend of rubber plantations replacing natural forests in some countries like China and Indonesia. On the social side of impact, current research focuses on assessing the impact of rubber plantation on livelihoods. Some researchers find that rubber plantations have succeeded in improving the livelihoods of citizens in areas where rubber plantations have expanded.

It can be observed that current research focuses on assessing the impact of rubber plantation expansion. Replanting activity is not fully assessed in contemporary research, although this activity crucial for maintaining rubber supply while the available area for plantation expansion is limited. Furthermore, in current research, current and future rubber supplies are not considered to be an impact of rubber expansion. This contrasts with the aims of sustainable development, which are generally geared towards the fulfilment of current and future demand. Moreover, current research only tends to focus on one two dimensions of sustainability. The investigation of three dimensions of sustainability simultaneously is rarely found in recent assessments of the plantation stage.

In term of tools for assessing sustainability, economic assessments such as net present value, land expectation value, and life cycle assessment are widely used by researchers. As a result, the focus of recent assessments tends towards singular plantations rather than plantation networks. Integrated sustainability assessments are rather neglected by academics, despite this method being able to assess the impact of activities within the network.

2.3.3 Selection of Methods for Integrated Sustainability Assessment

This section assesses factors in the selection of appropriate methods for integrated sustainability assessments, and presents a review of the implementation of system dynamics and agent based simulation for assessing sustainability. De Ridder et al (2007) define integrated assessments as the acceptance of all assessment models and tools as long as some formats of integration are employed, some issues related to sustainable development are included, and assessments are designed to support decision-making.

Hamilton et al. (2015) define integration as an effort to combine different elements such as tools, disciplines, scales, etc. Jakeman & Letcher (2003) identify five dimensions of integration in integrated assessments, including issues, stakeholders, models, disciplines, and processes. Hamilton et al. (2015) include integration within ten dimensions, including the issue of concern, governance setting, stakeholders, human settings, natural settings, spatial scales, time scales, disciplines, methods and uncertainty.

The first variable for integration comprises the issue of concern. Integration in this dimension emerges after interdependency between issues is detected. For example, reducing natural rubber supply not only generates an economic impact for downstream industries and governments, but also has an environmental impact by reducing carbon stock. The second variable is governance setting; implementation of governmental intervention to system processes may produce different outcomes. Integration in this sense comprises forms of interventions from governmental or private institutions into system processes.

The third variable presented is stakeholders. Integration in this section means that stakeholders are involved in developing an integrated assessment model and involved in its implementation. The fourth variable is the human setting. In assessing policy, human elements such as populations, behaviours, and decisions must be integrated owing to their massive impact on the performance of policy. The fifth variable relates to natural setting; this integrates components of the biophysical system into the assessment process. The sixth variable is spatial scale; in this sense, the integrated assessment must be able to capture multiple scales of system processes.

The seventh variable is time scale. One advantage of integrated assessments is their ability to capture the multiple time scales of a given system. For example, to calculate the contribution of natural rubber supplies to the government, a yearly supply measurement is preferred. On the other hand, to calculate the contribution of plantations to smallholders, daily or weekly production data is preferred. The eighth variable is discipline. The increasing complexity of systems necessitates the integration of knowledge from different disciplines, including ecology, economics, agriculture and biology.

The ninth variable comprises methods and tools. Each method and tool has limited features. Complex systems require a greater number of features. As a result, the integration of two or more methods and tools is required to fully grasp complex systems with different spatial and temporal scales. The tenth variable is uncertainty; many factors can cause uncertainty within a system, from nature (weather, climate) to human-oriented factors (knowledge, decisions, behaviours). These uncertainty factors can influence a system’s performance. As such, integrated assessments must factor for the integration of uncertainty.

2.3.3.1 Factors Influencing Methods Selection

This section presents critical factors in selecting methods for integrated sustainability assessments. One important component in the development of integrated sustainability assessments is methods selection. This activity is used to locate suitable methods that align with the nature of the problem and the objective of the assessment. Gasparatos and Scolobig (2012) propose an approach to find appropriate methods. The authors suggest selecting methods based on:

- The desired perspectives of assessment, i.e. methods are selected based on the motive and objective of assessment. For example, if an assessment is intended for the collection of information related to resources of consumption and the impact of policy, then biophysical methods may be appropriate.
- The desired feature of the sustainability assessment. This means that methods are selected based on the ability of those methods to generate analyses related to sustainability. Some methods can generate analyses of the three sustainability pillars simultaneously, while other methods can only provide analyses for one sustainability pillar. Gasparatos and Scolobig (2012) categorise the capabilities of methods into:

    - The ability to assess economic, environmental, and social issues, and their interrelations (triple-bottom-line assessment)
    - The ability to generate project or policy impact into future
    - The ability to perform distributional assessment
    - The ability to capture uncertainties, or the need to act on a precautionary basis
    - The ability to ascertain the needs, value, and expectations from related stakeholders (participatory assessment)
- The acceptability criterion of adopted methods, i.e. methods can be selected based on the ability of methods to support the acceptability criterion adopted by stakeholder. There are three types of acceptability criterion: the minimization of negative economic, environmental, and social impacts by allowing a trade-off between sustainability issues, and the maximisation of positive economic, environmental, and social impacts by avoiding trade-offs and focusing on improving the sustainable/unsustainable balance in outcomes.
- The value of related stakeholders. This means that methods can be selected based on the value of related stakeholders. There are three types of stakeholder's value orientations: concern for other humans, concern for non-human species, and egoistic concerns (self-interest). For example, monetary tools will align with the values of stakeholders who have specific concerns around human value.

Another approach for methods selection is proposed by Sala et al. (2015). The authors introduce a framework consisting of criteria and sub-criteria. The following comprise the criteria and sub-criteria for methods selection:

- Boundary-oriented-ness (no reference, reference value from scenario, science/policy based thresholds)
- Transparency (closed model, partially open model, open model)
- Strategic-ness (Accounting, Sustainability principle oriented, Change-oriented)
- Scalability (local scale and limited timeframe, spatial scale and temporal, multi temporal and spatial scale)
- Stakeholder involvement (Communication, Resonance, Interaction)
- Integratedness (mono-disciplinary, multi or interdisciplinary, transdisciplinary)
- Comprehensiveness (one pillar, two pillars, three pillars)

Kelly et al. (2013) introduce additional criteria for methods selection, including:

- Model purpose; this means that methods can be selected based on the values of modelling. As a method, modelling can be used for prediction, forecasting, management, and decision-making, as well as social learning and increasing system understanding.
- Type of data available; the method can be selected based on data available to support the assessment. There are two types of data for model construction: qualitative and quantitative data.
- System conceptualisation; certain components or entities of the system in focus can influence methods selection. These factors incorporate three elements: space, time, and structure.
- Treatment of uncertainty; methods are selected based on their ability to factor for uncertainty. For example, system dynamics and agent-based models require comprehensive testing to investigate the impact of uncertainty into outcomes.
- Ways that methods generate output; methods are selected based on the ways they generate output. There are four ways that methods generate output, including the scenario approach, analytic approach, optimisation approach, and multiple objective approach.

In the present research, the purpose of assessment is to ascertain the sustainability impacts of replanting for the planning of replanting policies in the upstream natural rubber supply network. This network comprises a complex system consisting of several entities, all of which are interconnected and deliver natural rubber to the next stage of the natural rubber supply network. The performance of this supply network changes dynamically over time, owing to the life cycle of rubber plantations. This network furthermore consists of several key agents, from rubber smallholders to village suppliers. Behaviours and interactions between these agents influence the performance of the supply network. Given this problem, the purpose of assessment, the scope of assessment, the system description, and the system dynamics simulation all emerge as appropriate tools for understanding the relationship between entities in this complex network. Using these tools also aids in our ability to understand the dynamics of supply networks. Agent-based simulation can also be used as an appropriate tool for grasping the interaction between key players in the upstream natural rubber supply network.

2.3.3.2 System Dynamics as a Sustainability Assessment Method

This section introduces the implementation of system dynamics as a model for assessing sustainability in extant literature. The implementation of system dynamics for the assessment of sustainability was initially explored by Meadows and de Rome (1974) in research around limits to growth. Although the authors faced substantial criticism from academics relying on modelling assumptions, their framework has succeeded in describing the connections between humans' activities and earth systems. As a result, a recommended reduction in the exploitation of natural resources has become mainstream, due to the significant impact that such exploitation has on the earth's overall system. Following the implementation of this recommendation, the popularity of system dynamics in supporting sustainability goals has increased significantly. The implementation of system dynamics can be seen in energy, water, and agricultural management.

The main benefit of system dynamics is in its ability to locate interdependencies and relationships between the entities and elements of one system. This is significant because an interventional development or policy usually focuses on manipulating just one entity (one sub system). Employing system dynamics instead extends the impact of this manipulation to an observation of the behaviour of a whole system. This approach helps researchers to move from a linear-thinking perspective to a non-linear perspective, from a property-focused analysis to relationship-focused analysis, and from a static-one-factor-analysis at one specific time to a dynamic-whole system-analysis (Nabavi et al., 2017).

An additional advantage of system dynamics is in its ability to provide and predict long term sustainability impacts (Ness et al., 2007). Using system dynamics, researchers can ascertain an impact prediction of system behaviours in future years, which has important implications for the guiding of sustainable development. This aligns with the viewpoint that considers sustainable development as a process rather than a project. To elaborate: sustainability comprises an ideal state of a given system, whereas sustainable development is rather an on-going process that is carried out to achieve that ideal (Nabavi et al., 2017).

The implementation of system dynamics has increased significantly in the evaluation of sustainability within the agricultural industry. Agriculture involves diverse components that interact in complex ways (Walters et al., 2016). External factors such as regulations, economic circumstances, and the behaviour of stakeholders all serve to influence the performance of the industry. System dynamics can offer one approach for understanding this complexity and for increasing understandings of the system overall (Kelly et al., 2013). System dynamics have been used to investigate the impact of agricultural policy in one sustainability dimension, as is seen in the work of Dace et al. (2015), and in work that incorporates the full spectrum of sustainability dimensions, as is evidenced in the work of Espinoza et al. (2017).

The implementation of system dynamics at the sourcing stage in the agricultural industry has been explored by several researchers for numerous crops, as is seen in the work of Choong and McKay (2013) and Espinoza et al. (2017) for palm oil, Ferreira et al. (2016) for citrus, Arshad et al. (2015) for cocoa, and Mutanga et al.,(2016) for sugar cane. All of these researchers simulate the impact of modifying variables at the plantation stage into their sustainability indicators, e.g. levels of production, greenhouse gas emissions, electricity production, and energy production.

Choong and McKay (2013) demonstrate palm oil plantation growth from the planting stage to the end of the productive phase. Plantation growth has been influenced by the density of trees in plantations. The main issue investigated by the researchers is the impact of plantation supply on emissions, waste, and energy produced by a processor who received the plantation supply. Espinoza et al (2017) employ a similar approach in their modelling of palm oil plantations. The authors here observe the impact of national consumption of palm oil and profitability of palm oil on the expansion of palm oil plantation areas. New areas for palm oil plantation are predicted as being provided by tropical forestland and agricultural land for food production.

Arshad et al (2015) model the production of cocoa based on changes to cocoa plantation areas. The researchers ascertain that cocoa plantation areas are changed or reduced owing to their conversion into palm oil plantations. A similar approach is conveyed in the work of Mutanga et al. (2016) who model sugar cane plantation areas. The authors explore the conversion rate of agriculture land into sugarcane areas and conversion rates of sugarcane areas into other crops in their formulations of future sugarcane plantation areas. To construct a scenario for future sugarcane production, the researchers use spatial data of sugar cane plantation areas.

Nevertheless, there are no plantation models proposed by researchers that capture the life cycle of plantations. In predicting cocoa plantation areas (Arshad et al., 2015) and sugar cane plantation areas (Mutanga et al., 2016), the life cycle of cocoa plants and sugar cane plants are not captured. For instance, cocoa has an immature phase and becomes productive after 3 years. Cocoa also faces a productivity reduction after 20 years. Yet in simulations, all plantation areas are considered to have the same age. In reality, plantations may be planted at different times resulting in distributions of age within the plantation network that influence production levels in that network.

Another important issue that is not generally considered in recent plantation models is replanting itself. Although replanting is a key activity for sustaining supply from current plantation areas, the expansion of plantations is limited because of the availability of land. Subsequently, plantation areas enter low-productive phase and cannot be returned to complete productivity in simulations. In some low-productive area, however, replanting can return a plantation to some productivity. These variables may lead to significant error in predicting productive plantation areas, in turn influencing the prediction of supplies from a given plantation.

Cocoa and natural rubber plantations are dominated by smallholder plantations. The productivity of these plantations depends on the behaviour of smallholders in their cultivation of plantations, and how they harvest plantation products. It is therefore necessary to gauge smallholder behaviour accurately. One important decision facing smallholders is whether to stay with old crops by replanting, or to change crops. This decision is influenced by numerous external factors including profitability, cultivation costs, and replanting cost. Current models are insufficient for gauging these decisions at the plantation stage.

The implementation of system dynamics in modelling natural rubber plantations is arguably rare. This presents an opportunity to implement system dynamics for modelling natural rubber plantations, a process that engages with the life cycle of rubber plants and the behaviour of rubber smallholders.

2.3.3.3 Agent-Based Simulation as a Sustainability Assessment Method

This section reviews literature around the implementation of agent-based simulation to assess sustainability. Improving sustainability in one region, community, or system may require an implementation of policy. Policies are usually arranged around interventions that advance changes in the current process, production, technology or behaviour exhibited by the targeted system. However, successful policies are usually influenced by the targets of policies. These targets can comprise communities, organisations, companies, or individuals. Naturally, the characteristics of these organisations, companies or individuals influence the success of policy implementation. At this stage, an agent-based model that can gauge the behaviour of individuals or a group of individuals presents a key opportunity for supporting the analysis of the impact behaviours on policy implementation. Agent-based models can construct a picture of emergent behaviours that result from interactions and learning processes among individual entities (Kelly et al., 2013).

This particular ability of agent-based models have attracted researchers to the implementation of this approach in assessing policy across many sectors such as transport, energy, agriculture, healthcare, and business. For example, Villamor et al., (2014) have investigated the impact of different scenarios on land use change and biodiversity in Jambi, Indonesia. One of these scenarios comprises a payment for ecosystem (PES) service, which offers an incentive for farmers by buying farmers' products at a higher price if they change their land use to an environmentally friendly model such as agroforestry. Results indicate that the PES scenario generates improvements in biodiversity and agroforest, compared with a business-as-usual scenario. The research also allows us to understand household behaviour in Jambi, through collating data through surveys. Household behaviour is then predicted by implementing multinomial logistic regression and binary logistic regression on survey data.

A similar approach has been conducted by Marvuglia, Rege, Navarrete Gutiérrez, et al. (2017) to model future crop patterns in Luxemburg. Using survey data gained through web interviewing techniques, the behaviour of farmers was illustrated. In their research model, farmers' behaviour related to decisions to select crop for their land by considering selling prices and the impact of crop growth on climate change. This scenario was designed through modifying the green consciousness of farmers. Green consciousness relates to the level of farmers have for the impact of crop production on climate change. Implementing different scenarios such as these has produced different perspectives of future crop patterns, which in turn result in differentiated impacts on climate change.

The implementation of agent-based models in supply networks has been demonstrated by Long, (2015). The author here suggests that material, information, and time flows are important aspects in the modelling of supply network evolution. Organisations or key players within the network are interconnected by material flows between them. This interconnection occurs while demand of material from and to organisations is delivered via a flow of information. Both the material flow and information flow occur at discrete times within a time flow. This paper suggests that material and information flows are influenced by the decisions of key players within the supply network. For example, at the plantation stage, the decisions of smallholders to sell their products are influenced by many factors such as harvest time, warehouse capacity, and price, among other factors.

The implementation of agent-based models to assess policy and to generate impact on sustainability performances has increased significantly. The implementations of agent-based models in assessing the impact of policy into material flows in supply networks are nonetheless not as numerous, particularly at the sourcing stage in the agricultural industry. The behaviour of key players at this stage, particularly of farmers, is a critical issue in the management of material flows within agricultural supply networks.

2.3.3.4 Integration System Dynamics and Agent-Based Simulation

The increasing complexity of systems has contributed to exacerbated difficulties for modellers in simulating real systems by using one method of modelling. Despite the modelling objective of simplifying real systems, sometimes the crucial components or parameters of a system cannot be understood accurately by employing just one method of modelling. For example, supply networks for one product involve different organisations and firms. These organisations are grouped into different tiers or stages. System dynamics can be used to model the relationship between tiers or stages. Nevertheless, this modelling method still fails to model the interaction between organisations at every tier through analyses of their behaviour.

The emergence of sustainability as a concept has attracted researchers to integrate this issue into modelling systems. The development of a widespread sustainability definition, which is now displayed in three dimensions – economic, environmental, and social – has rendered one singular modelling method for the presentation of results for all sustainability dimensions insufficient. Difficulties arise when the focus of sustainability is not only at the top levels of regional and national processes, but also at the bottom level, concerning people, citizens, and community. As a result of facing the challenge of multi-methods, modelling has now emerged to address these problems.

According to Borshchev (2013), the combinations of different modelling methods are, in practice, infinite. The nature of systems, the boundaries of modelling, and the objectives of modelling, all influence the ways that modelling methods are combined. There are several combinations of models that have been implemented by researchers and academics. These include combinations of system dynamics, discrete event simulation, and agent-based simulation. These combinations can be shown in several forms, including through agents in system dynamics environments, agent-interaction with process models, process model relationships to system dynamics models, system dynamics within agents, processes within agents, and agents as entities within a process (Borshchev, 2013).

In contemporary thinking, the combination of agent-based models and system dynamics comprises one multi-method that has the efficient capability of gauging complex and adaptive systems. According to Kelly et al. (2013), the agent-based model aligns more predominantly with the elements of a system relating to the individual, rather than to the observable aspects or to the equation. System dynamics instead provide a stock and flow diagram, which connects the entity or variable resulting from measurement, or the equation, rather than the individual. As a result, system dynamics begins from formulating the equations that express relationships among parameters, whereas agent-based models begin with detecting the behaviour of each individual. Furthering this, Lättilä et al. (2010) find that agent-based models and system dynamics are complementary, where system dynamics function as an effective choice for highly aggregated modelling, and agent-based model functions as an effective choice at the lower level (the level of the individual).

This combination of agent-based models and system dynamics has been used by many researchers in different ways. Gaube et al. (2009), for example, use agent-based modelling to analyse the behaviour of farmers cultivating their land in a region of Austria. The activities of farmers directly influence the system of carbon balancing which has been developed through system dynamics. Kieckhäfer et al. (2009) investigate the impact of production costs on the price of car sales, and the influence of fuel prices on consumer choices around vehicle technology, by combining a system dynamic model with an agent-based model. In this way, consumer choice is used as the basis for manufacturing decisions around the type of product to be made. Pasaoglu et al. (2016) demonstrate the use of system dynamics for modelling future transitions in power train technology. The parameters of system dynamics in their model are generated through using an agent-based model. Interactions between four market agents consisting of users, manufacturers, infrastructure providers, and authorities influence technology transitions in the light duty vehicle sector. Akopov et al. (2017) demonstrate the way system dynamic simulation can be used to support agents decision-making. In their model, system dynamics are used for calculating the economic impact of company actions. This calculation is used by the company (and its agents) to formulate decision as to whether it will pursue ecological policies.

Based on recent researches that implement combinations of system dynamics and agent-based model, Vincenot et al. (2011) show different combinations of agent-based frameworks and system dynamics. The first combination presented is an agent-based model combined with system dynamics to gauge dynamic properties in the environment. The second combination comprises a system dynamics model embedded within an agent-based model. The third combination is an agent-based model combined with system dynamics as an environment and agent-based model – system dynamics can therefore involve multiple combination and switched roles.

Figure 2.6 shows a different approach to building a hybrid model between system dynamics and agent-based models, as proposed by Swinerd and McNaught (2012). The first combination is an integrated hybrid design. In this approach, system dynamics and agent-based models can be integrated in three ways: a system dynamics module can be located within the agent; a system dynamic module can be built from the aggregating measurement of agent modules (stock agent); and the output resulting from agent behaviour can be used to influence parameters within the system dynamics module.

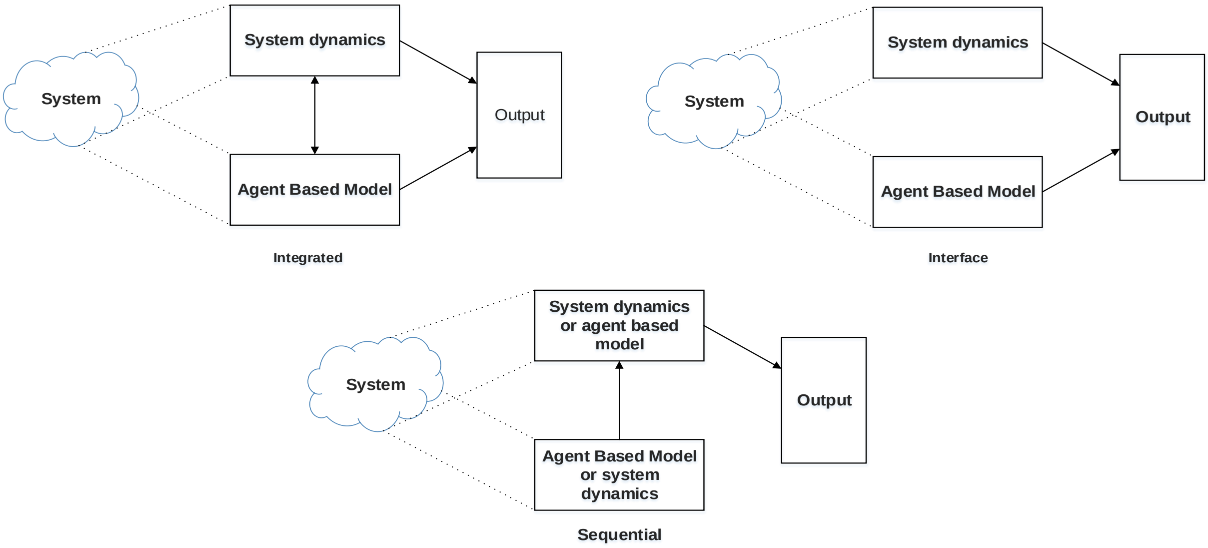

Figure 2.1 Approaches to integrated system dynamics and agent-based hybrid models (adapted from (Swinerd and McNaught, 2012))

The second combination comprises an interface hybrid design. This hybrid design is described as an agent-based model that is run simultaneously with system dynamics within the same environment. Both simulations produce outputs from the same environment, although there is no direct interaction between agent-based models and system dynamics. This approach can be used if the modeller wants to gauge differents view of systems (upper level and bottom level). The third combination comprises the sequential hybrid design. This design provides one type of modelling that is used as a starting condition for another type of modelling. In other words, both models do not run simultaneously, and instead, one model will runs first in order to generate information for another type of model. Finally, the emergence of multi-modelling methods is influenced by the growing shifts of modellers towards representing interdependencies between different levels of a system hierarchies or scales.

System dynamics offer the ability to ascertain different entities within a complex system, as well as the ability to connect the performance of the system with its sustainability dimensions (Walters et al., 2016). Agent-based models, on the other hand, offer the ability to understand the behaviour of key players and to gauge the impact of those behaviours (Kelly et al., 2013). The integration of these two methods presents the opportunity to illustrate complex systems like supply networks, and to improve the capabilities of modelling (Swinerd and McNaught, 2012). Since integrated assessments require some form of integration (De Ridder et al., 2007; Sala et al., 2015b), the integration of system dynamics and agent-based models opens up further opportunities to engage with several forms of integration, e.g. the integration of time, spatial, methods, and human settings. Nevertheless, the implementation of hybrid simulations models of system dynamics and agent-based approaches as integrated assessments are not numerous in literature, particularly with regard to the assessment of rubber replanting policies in upstream natural rubber supply networks.

2.4 Overview of Planning Models in Upstream supply network

The above discussion of sustainable supply networks highlights the importance of the planning process at the sourcing stage. As is seen, the sourcing stage is fundamental for the supply of raw material to the next stage of the supply network. This section is split into three parts: section 2.4.1 presents a planning model for optimum sourcing; section 2.4.2 introduces a model trade-off to support planning; and section 2.4.3 introduces dynamic programming.

2.4.1 Planning Models for Optimum Sourcing

This section introduces recent planning models for determining optimum sourcing. In supply networks, downstream organisations across the network receive supplies of raw materials from the sourcing stage. These materials include latex from rubber plantations in the natural rubber supply network. Defining optimal output from sourcing is a key decision in the smooth operation of this process. Tsolakis et al (2014) categorise this decision as a strategic one, as well as a main component in configuring supply networks in the agricultural industry. While it is challenging to design and plan all future actions for determining optimum sourcing in the network, it is necessary to define appropriate directions so that this can be achieved. This requires a comprehensive insight and accurate forecast of supply networks' future circumstances. The optimum source should be ascertained without creating adverse effects to surroundings. The three dimensions of sustainability are therefore pertinent in the consideration of planning processes for optimum sources. To address these challenges, researchers and academics in this field have proposed numerous models and tools to support decision-making for optimum sourcing.

Bouchard et al (2016), for example, propose an integrated model in forest planning. In this instance, an integrated model consists of a forest management model and logistic model. The natural growth of a tree in a forest with spatial distribution is gauged using a forest management model, while a logistical model presents flows of timber through several processes after harvesting. Zhai et al (2014) introduce bi-level programming with genetic algorithms to support planning for fast-growing plantations. This model consists of an upper-level programme to capture the age structure of plantations, and a low-level programme that functions to maximize the economic benefits of harvesting. Ahumada & Villalobos (2011) introduce a planning model for planting tomatoes and peppers, taking into account more traditional factors such as price, inventory cost, and transportation cost. The authors here improve upon the previous model by gauging uncertainty factors in planning models for planting tomatoes and peppers (Ahumada et al., 2012). Recent models have contrastingly lacked a network perspective and have failed to capture the dynamics of sourcing capacities in the agricultural industry. Bouchard et al. (2016) and Zhai et al. (2014) have introduced models to ascertain area and the structural age of plants, but these models have no network perspective and focus on a certain areas only. Furthermore, recent models do not adequately consider the three dimensions of sustainability.

Some researchers have provided an overview of tools that are used to support decision making in allocating optimum sources. Ahumada and Villalobos (2009) categorize models based on operational activities supported by models including production, harvesting, operations, and distribution. The authors find that deterministic models such as linear programming, dynamic programming, mixed integer programming, goal programming, and stochastic models such as stochastic dynamic programming, simulation, and risk programming are dominant in research around support planning in agrifood. Kusumastuti et al. (2016) categorize models based on supply chain stages that have been ascertained in recent research around models. For example, some papers only cover harvesting, some cover cultivation and harvesting, and some papers cover harvesting and transportation to pre-processors, among other aspects. The authors find that an integrated model is required to solve complex agri-chain problems. Integrated models are theoretically able to provide better insight into different stages of supply networks, as well providing a clearer picture of the impact of decisions into sustainability in supply networks.

Across existing literature, the majority of available planning models for optimum sourcing are constructed for short-term plants, such as tomatoes and peppers. Planning models for long-term plants like rubber, palm oil, and cocoa are not numerous in contemporary research. For long-term plants, decisions around planting and replanting are strategic. Long-term plants require comprehensive planning owing to their long life-cycle and the difficulty of crop switching. Furthermore, in recent models, the trade-off between the three dimensions of sustainability is not something that is completely implemented. The majority of planning models consider the economic dimension only. Recent planning models are also generally created to support one singular area and are not oriented around a network perspective.

2.4.2 Trade-off models to support planning at the sourcing stage

The implementation of sustainability measures can create additional adversities for planners and stakeholders in the supply network. These challenges relate to the counterbalance between the three dimensions of sustainability, and deciding which dimension is more important than other dimensions for strategic decision-making in the supply network. In reality, planners are unable to improve all dimensions simultaneously, as improving one dimension can diminish other dimensions. As a result, the planner is required to make a compromise around sustainability dimensions when designing strategic decisions. This compromise is necessary for determining optimum replanting while minimizing adverse impacts to surroundings.

To address this issue, many studies have investigated and proposed trade-off models. One such trade-off model is mathematical: Longinidis & Georgiadis (2013) use multiple-objective mixed integer non-linear programming with Pareto optimality to ascertain a compromise between financial performance and credit solvency in designing supply networks in conditions of economic uncertainty. A similar approach is conducted by Zhang et al. (2014), who construct a trade-off between three sustainability indicators, including total cost, GHG emission, and lead time. Their model uses environmental data from company life-cycle assessment reports. However, mathematical models do not offer planners flexibility in emphasizing which dimensions are more important compared with other dimensions, based on the current conditions of networks and requirements of stakeholders or regulations. In some supply networks, owing to environmental damage, stakeholders and regulations have pushed planners to prioritize environmental indicators over other indicators.

Hassini et al (2012) propose composite indicators for assessing sustainable supply networks. Composite indicators generate a performance value calculated from the performance of each sustainability dimension and the performance of each dimension’s sub-indicators. In this proposed framework, indicators and sub-indicators are determined by planners in the supply network. The planner is moreover given the flexibility to determine the weight of each indicator and sub-indicator based on their degree of interest. Composite indicators are easily linked with other models that generate indicators’ data, including life-cycle assessment and simulation models.

Composite indicators are widely used by researchers and academics from different fields, including economics, engineering, healthcare, and agriculture (Rogge, 2012). This method’s popularity is generally owing to the inherent flexibility for planners in harmonizing degrees of interest between indicators, and the ability of composite indicators to aggregate different information from various indicators into one single value. However, one key susceptibility of composite indicators occurs in the weighting of indicators and sub indicators. At this stage, a high degree of subjectivity is unavoidable. Recent innovations such as equal weighting, data envelopment, and budget allocation process have nevertheless been developed to solve this issue.

Some examples of the implementation of composite indicators are be observed in the work of Areal and Riesgo (2015), Badea et al. (2011), Tajbakhsh and Hassini, (2014), and Zhou et al. (2010). A non-compensatory multi-criteria approach for calculating the composite sustainability index of a single company is presented by Zhou et al. (2010). The authors furthermore develop a sensitivity analysis for the comparison of results from the implementation of different methods for normalisation, weighting, and aggregation. Tajbakhsh and Hassini (2014) propose a framework to evaluate sustainability at different stages of supply networks using data envelopment analyses, and subsequently show how composite values from different stages are accumulated. Rogge (2012) presents the implementation of a benefit-of-the-doubt model in order to calculate the environmental performance index for 120 countries. Badea et al. (2011) introduces ordered weighted averaging for aggregating indicators and criteria for energy security supplies. Areal and Riesgo (2015) study the integration of probability functions within composite indicators and this is used to calculate environmental impacts resulting from genetically modifying crops. These examples show the ways that composite indicators can be implemented in different fields by applying different methods for normalisation, weighting, and aggregation.

Composite indicators offer several advantages for sustainability, from the ability to generate a single index to generating stakeholder participation. However, the implementation of composite indicators for trade-offs in the three sustainability dimensions are sparse in literature, particularly around the planning of sourcing in the agricultural industry. Since a supply network consists of different organisations or companies, where each carries out an operation to deliver products or services, the complexity of trade-off processes is heightened. Each organisation may have a different perspective on sustainability. Trade-off processes in supply networks are therefore not only between the three sustainability dimensions, but also between the sustainability goals of organisations within the network.

2.4.3 Dynamic Programming to Support Planning at the Sourcing Stage

Dynamic programming has been developed as a tool to define optimal solutions. Bellman's principle of optimality is used as the core theory of this programme. This principle argues that problems requiring decisions at different levels or stages must be solved by interrelated series of decisions. The interrelatedness of decisions can be gauged through defining optimal solutions for remaining decisions, based on optimum solutions that result from previous decisions (Yadav and Malik, n.d.). In other words, Bellman's principle requires the division of problems into sub-problems whereby optimum solutions are defined sequentially for each sub-problem. Supply networks comprise one field for the implementation of dynamic programming. The configuration of key players within a network can be summarised as a dynamic programming problem. Dynamic programming may be used, for example, in determining the total number of suppliers required to flow raw material from rubber plantations to primary processors in upstream natural rubber supply networks.

Dynamic programming has been widely used by academics and researchers across different sectors and fields. In the transportation sector, for example, Otto and Boysen (2014) use dynamic programming to define locations for public transportation stops. In the energy sector, Fan et al (2016) implement dynamic programming to define the allowance level for trading and energy consumption, based on personal carbon trading schemes. In the medical sector, Astaraky and Patrick (2015) explore the application of dynamic programming for constructing multi-resource surgical scheduling. In the agricultural sector, Diban et al (2016) use dynamic programming to define optimum replanting times, by taking into account CO_2 emissions over the lifetime of palm oil. Dynamic programming offers an effective approach for solving optimisation problems in complex networks (Tripathy et al., 2015). However, in the field of supply networks, the implementation of dynamic programming is rare. This is confirmed in the work of Brandenburg et al. (2014), who review quantitative models for sustainable supply chains. The authors find that dynamic programming has only been employed in the work of Hu and Bidanda

(2009). Seuring (2013) delineates a similar trend by explaining that quantitative models are generally neglected in the field of forward sustainable supply chains, and in the quantitative models that are used, the majority of dimensions considered are environmental and economic. Only a handful of papers address the trade-off between the three sustainability dimensions in their quantitative models.

In the natural rubber industry, optimum sourcing is determined by optimum planting for new plantations, and optimum replanting for old plantations. The current approach for optimum replanting focuses on applying high-quality seeds and improving plant densities or the total number of rubber trees/ Ha (i.e. Sustainable Natural Rubber Initiative). The allocation of replanting influences current and future supplies by affecting future immature, productive, and low-productive areas. The allocation of replanting or the total area for replanting is nevertheless infrequently considered.

2.5 Research Gaps

Research gaps are presented here against the research questions.

"What are key requirements for the assessment of the sustainability of replanting policies in the Indonesian natural rubber industry supply network?"

Within the rubber plantation stage of the natural rubber industry, the focus of previous sustainability assessments has been on the expansion of rubber plantations that plant new rubber trees in land that has not previously been used for rubber crops (Z.F. Yi et al., 2014; Ahrends et al., 2015; Zhang et al., 2015; Nath et al., 2013). In contrast, this research focused on replanting of low productive rubber trees in existing rubber plantations. Planting and replanting activities have been a focus of recent research at the sourcing stage of agricultural industry. However, the majority of this research has concentrated on developing decision support systems to formulate decisions of planting and replanting for short-term plants (Kusumastuti et al., 2016) such as tomatoes and peppers (Ahumada et al., 2012). There has been limited research that focuses on long-term plants such as that demonstrated by Zhai et al. (2014) with bi level programming to plan fast-growing plantations and Bouchard et al. (2016) with integrated planning model to support forest planning.

Two key requirements in any assessment of sustainability were identified as being the availability of performance indicators and sustainability assessment tools (Sala et al., 2015). Performance indicators are used to quantify the economic, environmental and social performance of the targeted network which will be influenced by proposed policies. Sustainability assessment tools are used to determine values of those indicators and so quantify the effects of policy implementations. In line with previous sustainability assessment research, indicators in the natural rubber industry focus on representing the impact of new plantations in new land. For example, Wu et al. (2001) and Z.F. Yi et al. (2014) used profitability, Zhang et al. (2015) used forest area, Ahrends et al. (2015) used biodiversity and climate change and Nath et al. (2013) used people's livelihoods as indicators for rubber plantations expansion. However not all of these indicators are suitable to represent the impacts of replanting in existing plantations. Furthermore there are no specific sustainability indicators for rubber replanting introduced in contemporary literature.

Existing sustainability assessments of the expansion of rubber plantations use various tools including land expected value (Z.F. Yi et al., 2014), logistic growth model (Jawjit et al., 2010; Petsri et al., 2013) and ecological footprint (Musikavong and Gheewala, 2017). These tools focus on assessing the impacts of rubber plantations in one life cycle phase and one dimension of sustainability. However, replanting is a policy that influences the future composition of plantation areas which in turn affects three dimension of sustainability (economic, environmental and social) which include level of future supply, rubber smallholders' and suppliers' livelihood and level of carbon stocks. As a result, tools from previous research on the expansion of rubber plantations are not suitable for assessing replanting policies. This research focused on finding suitable sustainability indicators and establishing an integrated assessment tool for use in the formulation of sustainable replanting policies.

"What are necessary characteristics of an integrated assessment tool for use in the assessment of the sustainability of replanting policies?"

Integrated assessment has been widely used for assessing the sustainability impacts of policies and decisions in a number of sectors including agriculture, energy, transport and water (Kelly et al., 2013). There are several integrated assessment tools available in literature (Ness et al., 2007; De Ridder et al., 2007) and a number of researchers have identified specific characteristics of these integrated assessment tools. For example, system dynamics is good for assessing complex systems and their long term sustainability whereas agent based models are good for capturing individual behaviors and interactions between individuals (Kelly et al., 2013).

As a consequence, to assess specific policies in particular sectors, a suitable integrated sustainability assessment tool with specific characteristics is required (Sala et al., 2015). This is because the objectives of sustainability assessment used to inform policy decisions differ according to the purpose of the policy and the sector concerned. For example, the purpose of replanting policy in the natural rubber industry might differ with the purpose of replanting policy in the palm oil industry because they have different impacts on sustainability. Several researchers such as (Sala et al., 2015b; Gasparatos and Scolobig, 2012; Kelly et al., 2013) have introduced criteria to determine characteristics of integrated assessment tools that are required for assessing particular policies. These include the comprehensiveness, transparency, involvement of stakeholders and scalability of the tool. Since the focus of current sustainability assessments lies on the expansion of rubber plantations, there is no information in literature related to characteristics of integrated assessment tools for assessing rubber replanting policies. This research focused on identifying such characteristics.

“How might an integrated assessment tool be used to inform decisions related to the formulation of replanting policies in the Indonesian natural rubber industry supply network?”

The main aim of integrated assessment is to support decision makers in identifying which policies or decisions should or should not be taken in order to make society more sustainable (Rotmans, 2006). The review of literature showed how integrated assessment tools were used to assess sustainability impacts of policies in various sectors. For example, Hadian and Madani (2015) used a system of systems framework to assess environmental and economic impacts of alternative energy supplies, Ferreira et al. (2016) used a system dynamics approach to assess economic impacts of new oranges varieties and technology changes in the Brazilian citrus agribusiness and Delmotte et al. (2017) used a bio-economic model to assess environmental, social and economic impacts of mix-crops scenarios in Camargue, Southern France.

The majority of integrated assessment tools in literature were used only for calculating the sustainability impacts of policies. However, it is not clear in literature how integrated assessment tools can be used to inform the formulation of decisions and policies. This is because there was limited research that used integrated assessment tools to inform the formulation of policies such as that demonstrated by Van Delden et al. (2010), Gandolfi et al. (2014) and Bouchard et al. (2016). Moreover, there is no research that uses integrated assessment tools to inform the formulation of replanting policies in the natural rubber industry. This research focused on developing a method for using integrated assessment tools to inform decisions related to the formulation of replanting policies for the natural rubber industry in Indonesia.

Chapter 3
Research Methodology

This chapter presents the methodological framework and research design used in this research. The methodological framework consists of selected approaches, methods, and processes. The research design focuses on the selection of locations, participants, and techniques to implement the methodological framework. To present these issues, the chapter is divided into two sections. Section 3.1 introduces the methodological framework, which explains how the research problem directly influences the selection of approaches. Research methods are selected through evaluating research approaches and the research problem. Following this, the section outlines the research process design, which is mainly influenced by the selected approaches, methods, and objectives of the research. Each process in the research is connected to the fulfilment of research objectives.

Section 3.2 presents the research design. This section begins with determining the location of research in sub section 3.2.1. In section 3.2.2, the selection of data collection techniques is presented. Selection of techniques is mainly influenced by the type of data required in the project. This is followed by section 3.2.3, which determines the total number of participants required for collating sufficient data. The next sub section, 3.2.4, outlines the way that the study fulfils ethical requirements. Ethical review is a necessary component of research involving humans as research subjects, to avoid the violation of human rights and boundaries.

3.1 Methodological Framework

This section introduces the selection of approaches and methods, as well as the presentation of the research process design. According to Creswell (2013), the construction of a study’s methodology is mainly influenced by the research problem and research objective. The research problem comprises an object in real life that requires assessment. The problem can be identified through observation and discussion with related stakeholders, or by topics with significant impacts that are not addressed by academics and researchers in existing literature. The research problem is therefore unique in requiring different data and information that might be produced by specific approaches and methods.

3.1.1 Research Approach

According to Creswell, (2013), there are three research approaches that can be applied by researchers: a qualitative approach, a quantitative approach, and a mixed methods approach. Qualitative approaches focus on exploring individual or group perceptions and understanding human problems. ‘New’ problems are discovered where data and information related to a specific problem are insufficient. As a result, variables or entities that influence the problem are not gauged, obstructing the implementation of exact measurements and predictions. The qualitative approach can be categorised into either narrative research or phenomenological research. Narrative research focuses on examining the life of an individual or group and then using this information to construct a narrative chronology, while phenomenological research focuses on describing phenomena from the view of individuals who have interacted with it (Creswell, 2013).

Contrastingly, quantitative approaches examine problems by finding interrelations among selected variables and problems, using exact measurements and predictions. At the initial stage of research, several types of research are produced that relate to similar problems. Researchers begin with sufficient data and variables related to particular problems. This approach can be categorised as either inferential research, experimental research, or simulation research (Kothari, 2004). Inferential research focuses on capturing and analysing characteristics that emerge from a specific population. Experimental research focuses on investigating effects through manipulating certain variables. Simulation research focuses on creating an artificial environment reflecting real life, and generating data by observing the response of this artificial environment to changes in variables or conditions.

Another approach comprises the mixed method approach. This emerges from the intermediate condition whereby related problems of prior studies are still pertinent and in a provisional form, and can be used to propose new constructs (Edmondson & Mcmanus, 2007). This approach assumes that a combination between qualitative and quantitative can provide a complete understanding of a problem under examination. This approach can be categorised into exploratory mixed approaches, explanatory mixed approaches, and convergent parallel mixed approaches. In the exploratory mixed approach, research begins with a qualitative approach and then uses information from the qualitative phase to conduct quantitative methods. Explanatory functions as the reverse form of exploratory, whereby the quantitative approach is initially conducted. Results from quantitative data are subsequently detailed and explained using a qualitative approach. Convergent parallel mixed approaches use both quantitative and qualitative approaches at the same time, with a view to constructing a comprehensive analysis of problems.

Edmondson and Mcmanus (2007) offer guidance as to the selection of suitable approaches, based on the maturity of topics. They divide topic maturity into three types: nascent topics, mature topics, and intermediate topics. Nascent topics occur when new questions arise from new connections between phenomena. In contrast, mature topics occur from well-developed theories or models generated by the widespread work of researchers. Intermediate topics are positioned between nascent and mature topics, and occur when new issues emerge and need to be integrated into current models or theories, or current theories that are still provisional require new constructions.

As stated in the introductory chapter, the current problem in Indonesia's natural rubber industry is the reduction of its natural rubber supply from plantations. At the same time, the desire to improve sustainability has emerged from related stakeholders in the industry. This leads to the problem of sustaining natural rubber supply through considering the sustainability impacts of supply. To address this problem, approaches are needed that can assess sustainability and plan future supply growth in the industry.

Rubber replanting has been investigated by academics and researchers from different perspectives, including economic and environmental angles. However, the integration of a supply network perspective with sustainability in the assessment and planning of rubber replanting prompts new questions around new constructs. As the current assessment and planning of rubber plantations focuses on determining impact in smallholders' income, the integration of supply networks and sustainability, as well as future supply, environmental impacts, social impacts, and other impacts to key players within the network are of important consideration. By considering the maturity of research topics, research problem, and research aim, mixed approaches incorporating a combination of qualitative and quantitative approaches are selected as the main research method.

The selection of mixed approaches also allows for the selection of hybrid simulations that integrates system dynamics and agent-based method for sustainability assessments. Both of these models require qualitative and quantitative approaches in their development phases (Espinoza et al., 2017; Dace et al., 2015; Ding et al., 2016). System dynamics and agent-based approaches require a qualitative approach at the beginning of their developmental phase. System dynamics require a conceptual model (causal loop diagram) that connects several entities in the natural rubber supply network, while agent based models require a narrative of behaviour of key players in the natural rubber supply network. These considerations contribute to the selection of exploratory mixed approaches as the main research approach for this study.

3.1.2 Research Method

All methods and techniques used by researchers in performing research can be summarised as research methods. Researchers need to select suitable methods for carrying out research so that sufficient data is collated for solving research problems. Method selection is mainly influenced by the given research problems and identified research approaches (Creswell, 2013). The scope of this research relate to Indonesia's natural rubber industry. Natural rubber supply and rubber replanting are phenomena in Indonesia's natural rubber industry that have become the main focus of research. Replanting is key to sustaining the natural rubber supply. However, if replanting is not managed properly, current and future supplies are at high risk. This risk is brought about by the imbalance of immature, productive, and low-productive areas in the natural rubber supply network. Since research problems focus on phenomena around rubber replanting and natural rubber supply, case studies offer an effective method for investigating the issues in a real-life context (Yin, 2013). Case studies can provide researchers with real examples of implementing rubber replanting, and can illustrate the trend in natural rubber supplies resulting from the implementation of rubber replanting.

Case studies can furthermore accommodate exploratory mixed method approaches. Yin (2013) suggests that case studies can be used in both a qualitative and quantitative manner. The flexibility of case studies opens wider opportunities for the exploration of policy implementation processes. For example, Leigh and Li (2014) use a case study to explore initiatives by a company in increasing its environmental performance. Fu et al (2009) use a case study to observe the livelihood impact of policies to expand rubber plantation, as well as impacts on land changes and biodiversity. Case studies also provide information about sustainability criteria that are necessary for assessing production processes, as is demonstrated by Duarte et al. (2013).

Case studies can be used to give an understanding of agricultural systems and supply networks that differ owing to the type of plant grown. For example, cultivation of citrus differs from cultivation of the rubber tree. Furthermore, the configuration of supply networks for each plant can also vary. Ferreira et al (2016) use case studies to enhance understandings of the Brazilian citrus growing system. Case studies can also create a picture of the behaviour of key players systems under examination. This behaviour influences a system’s performance. For example Smajgl and Bohensky (2013) demonstrate how the behaviour of agents is derived from the real population in East Kalimantan, Indonesia and Marvuglia et al. (2017) derive agent behaviour from a population of farmers in Luxemburg. Another reason for using case studies lies in their ability to provide data for conducting tools of experimentation. This has been demonstrated by researchers like Akopov et al. (2016), who use real company data in Armenia to demonstrate agent-based policy assessment tools.

From the above discussion, the reasons for using case studies as research methods can be summarized as such:

- Case studies can accommodate qualitative and quantitative approaches
- Case studies can provide understandings of the natural rubber industry system including its supply network, characteristics of plants, and the implementation of replanting
- Case studies can provide information related to sustainability criteria that are used in the natural rubber industry
- Case studies can provide information related to the behaviour of key players in the natural rubber supply network
- Case studies can provide data and information for experimental tools and models

A single case study can therefore selected as an adequate research method. According to Yin (2013), there are five ways to use a single case study design; when a single case represents a critical case in testing a theory; when a single case represents an extreme case or a unique case; when a single case is representative or is a typical case; when a single case is a revelatory case; and when a single case is a longitudinal case. The first point refers to the ability of case studies to meet all the conditions for testing a theory. The second strategy refers to the condition whereby a selected case shows a different trend compared with other, similar cases. The third reason refers to the condition whereby a selected case is representative of a wider system. The fourth refers to the accessibility of the case, something that can be obtained when the research operations are run. The fifth point relates to time, whereby the case is investigated in the past, and observations are conducted again in a contemporary context, so that to changes in certain conditions over time can be detected.

3.1.3 Research Process

The research process describes series of actions and steps to perform research. Research processes need to be designed to gauge all necessary actions and achieve research aims and objectives. Every step in the research process can be performed sequentially or in parallel. According to Kothari (2004), steps in the research process are not mutually exclusive, separate, or distinct. In designing the research process, approaches, methods, and research objectives must be considered. Furthermore, the selection of methods for assessing the impact of replanting policies influences the research process by integrating the development phase of selected methods into the research process. As system dynamics and agent-based models are selected as sustainability assessment models for the evaluation of replanting policy impacts, the development phase for system dynamics and agent-based models must be integrated into the research process.

To accommodate the essential steps of the research process, including the investigation of case studies, the development of models, the validation and experimentation of models, and the application of proposed models, the research process is divided into three stages. The first stage in this process is oriented around the investigation of one case study. Exploratory mixed approaches are used to investigate North Sumatera’s natural rubber industry. Qualitative approaches are firstly implemented to generate a depth of understanding around the upstream natural rubber supply network. Interviews are conducted at this stage to generate information from relevant stakeholders in North Sumatera’s natural rubber industry. Interview data were analysed using thematic processes to generate detailed information related to entities in the upstream natural rubber supply network system, as well as to define operations performing by key players. Furthermore, influential factors affect key players’ decisions within the North Sumatera natural rubber supply network are also ascertained during this qualitative phase. All information from the qualitative phase is used to construct conceptual models and questionnaires for the quantitative phase. These conceptual models are evaluated by an expert panel and conceptual models are examined for their value in gauging all necessary entities, variables, and key players’ behaviours from Indonesia’s natural rubber supply network.

A quantitative approach is implemented after the qualitative phase. This approach is conducted to continue the investigation into factors influencing key players’ decisions. This approach is applied to identify significant factors affecting key players’ decision, as well as to develop decision models for key players. The decision models are used in developing strategic planning tool in stage two. A discrete choice survey comprises the main research technique used in implementing this quantitative phase. The survey is constructed through developing a questionnaire, which is in turn based on influential factors generated through the qualitative phase. An expert panel verified and validated the discrete choice questionnaire before the survey was conducted.

In the second stage, research activity is focused to develop an approach for the formulation of sustainable replanting policies. This stage is started by developing a process and determining sustainability indicators for formulating sustainable replanting policy. The information from the case study investigation and literature review is used in developing the process and determining indicators. This is followed by the development of a strategic planning tool for formulating sustainable replanting policies. Developments are initiated by determining requirements for the selection of appropriate methods. Following this, the system architecture for strategic planning tools is configured. This is followed by implementing system architecture into computerised models. Verification and validation of computerised models are then implemented by removing error, as well as by observing the behaviour of computerised models, whether or not they produce the desired output.

In the third stage, an approach is applied for formulating sustainable replanting policies in the North Sumatera natural rubber industry. The process of formulation replanting policies established in the second stage is subsequently employed to design the process that occurs in the third stage. The application of this approach is begun through determining replanting scenarios. At this step, an expert panel is involved in determining targeted districts and replanting scenarios. This is followed by the selection of sustainability indicators and also by determining the targets of indicators. An expert panel is also involved in this step. The following step involves the assessment of the sustainability impacts of replanting scenarios, by using the hybrid simulation models established. This is followed by determining the optimum replanting policy, by using composite indicators and dynamic programming models that are developed in the second stage. The methodological framework, consisting of research approaches, research methods, and research processes, is shown in Figure 3.1.

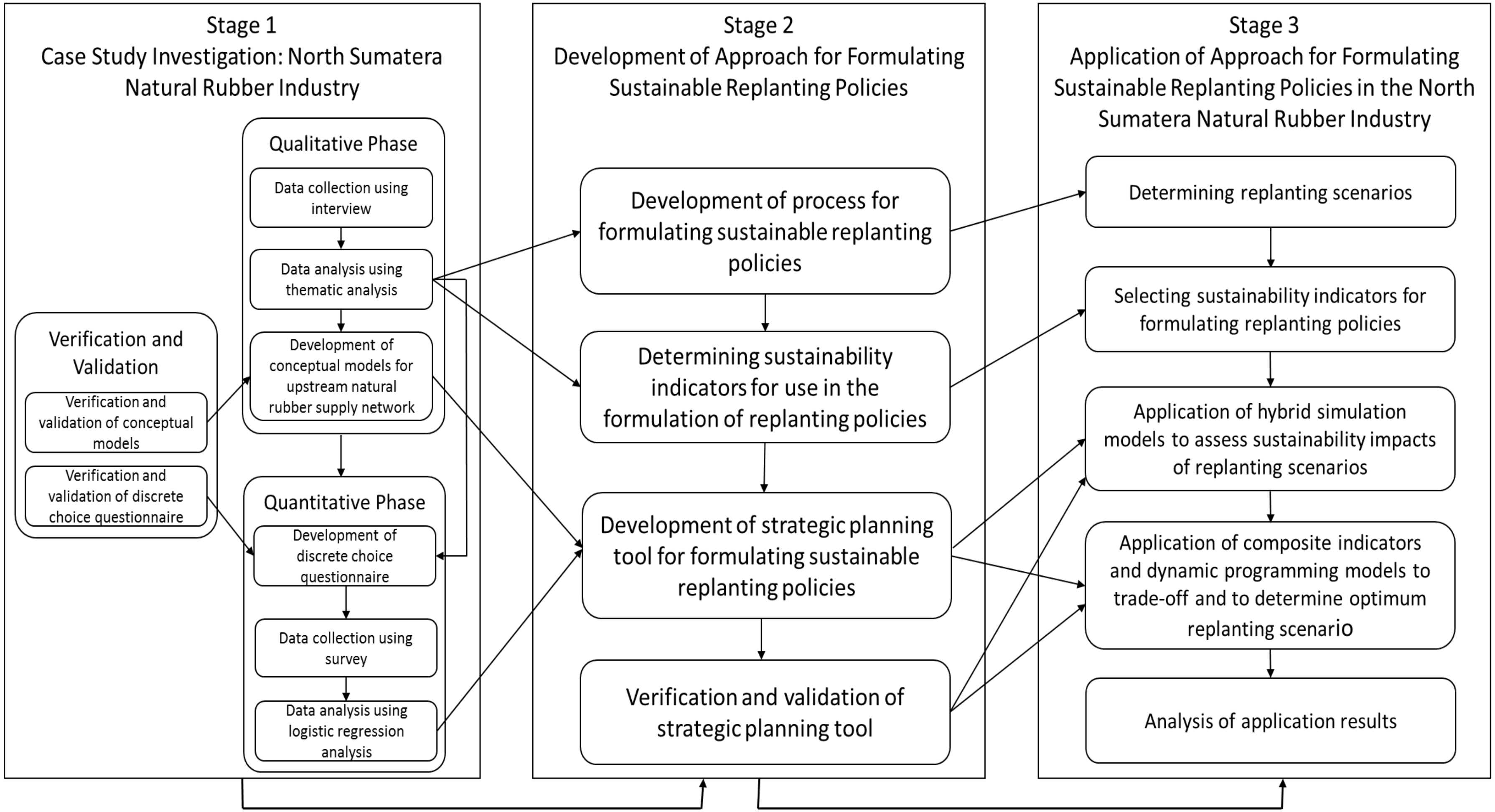

Figure 3.1 Methodological Framework

Table 3.1 The Relationship between Objectives within the Key Research Process

Stages	Steps	Objectives				
		1	**2**	**3**	**4**	**5**
One: Case study investigation of North Sumatera natural rubber industry	1. Data collection using interview		X	X		
	2. Data Analysis using thematic analysis		X	X		
	3. Develop conceptual models of upstream natural rubber industry		X		X	
	4. Verify and validate conceptual models		X	X	X	X
	5. Develop discrete choice questionnaire		X			
	6. Verify and validate discrete choice questionnaire		X			
	7. Data collection using survey		X			
	8. Data analysis using logistic regression		X		X	
Two: Development of approach for formulating sustainable replanting policies	1. Develop the process for formulating sustainable replanting policies	X			X	
	2. Determine sustainability indicators for use in the formulation of replanting policies			X		
	3. Development strategic planning tool for formulating sustainable replanting policies				X	
	4. Verification and validation sustainable replanting tools				X	X
Third: Application of approach for formulating sustainable replanting policies in North Sumatera natural rubber industry	1. Determining replanting scenarios for targeted districts					X
	2. Selecting sustainability indicators for use in the formulation of replanting policies					X
	3. Application of hybrid simulation models to assess sustainability impacts of replanting scenarios					X
	4. Application of composite indicators and dynamic programming models to trade-off and to determine optimum replanting scenario					X
	5. Analysis of application results					X

Every step in the research process is designed to achieve the objectives of research. The first stage of the research process is performed so that the second objective can be achieved. The latter comprises the identification of key issues in planning rubber replanting. The third objective of research is the identification of performance indicators for replanting. The second stage of the research process is implemented to achieve the fourth and fifth objectives of research, while the third stage of research process is executed to fulfil the fifth objective of research. Table 3.1 shows the relationship between key research processes in research and its objectives.

3.2 Research Design

The purpose of this section is to illustrate the implementation of the methodological framework. The research design is necessary for ascertaining maximum quantity of information and data through effective and efficient research operations. The research design involves the selection of research location, the devising of data collection techniques, recruitment of participants, and ethical consideration.

3.2.1 Location of Research

The North Sumatera natural rubber industry has been selected as a single case study. Early discussions with North Sumatera natural rubber stakeholders convey a reduction of supply across the industry. This reduction is also identified in many rubber plantations entering low-productive phase. This condition is thus suitable for testing the approach for formulating sustainable replanting policies. Furthermore, the North Sumatera natural rubber industry conveys an extreme condition whereby a significant reduction of supply has brought multiple impacts to primary processors. These processors have had to reduce the utilisation of their factories in order to address the reduction of supply. Another reason behind the selection of the North Sumatera natural rubber industry as a case study lies in its ability to be completely representative of Indonesia's natural rubber industry. The North Sumatera natural rubber industry has a complete network of significant key players, including rubber plantations, village suppliers, districts suppliers, traders, primary processors, and downstream industries. These key players are scattered in different districts, sub-districts, and villages in the North Sumatera province.

The North Sumatera Province consists of 33 districts. Rubber plantations can be found in 23 districts. However, owing to the limitations of time, cost, and access, not all districts in North Sumatera Province could be visited. Only five districts were selected and visited. All the participants in this research were chosen from those selected districts in North Sumatera Province. Figure 3.2 illustrated the selected districts to be visited in North Sumatera Province.

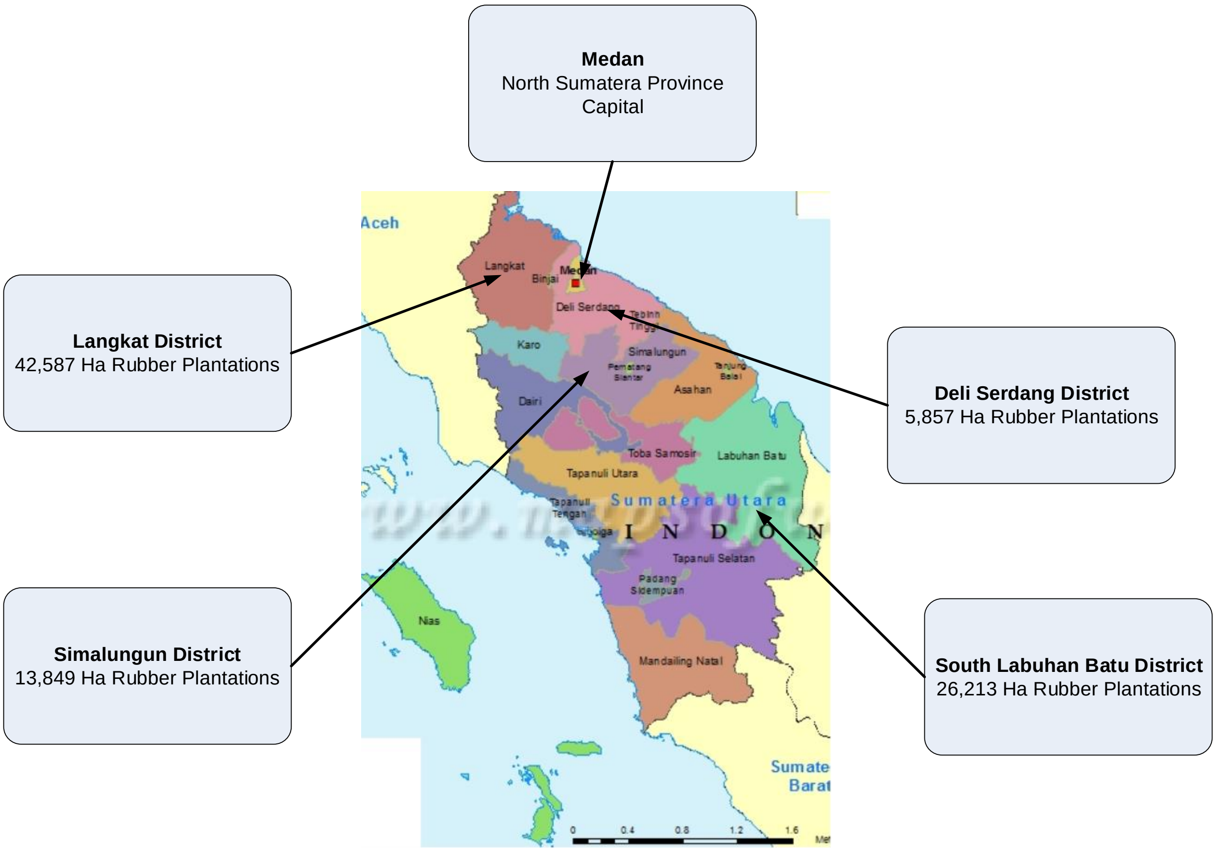

Figure 3.2 Selected districts at North Sumatera province (source: www.pendidikansejarah.com)

- Medan

  This city is the capital of North Sumatera Province. The North Sumatera Provincial Government is located here. All natural rubber product is exported through Belawan Port, located in the city. There are several primary processors and downstream industries located in the city.

- Langkat

  This district is located on the north side of North Sumatera Province. This district has the second biggest plantation area in the province. The district produces good quality of latex compared with latex from other districts in North Sumatera Province. Statistical data shows an increasing trend from 2001 in productive areas of this district. This contrasts with the general trend across North Sumatera Province, which has a decreasing area of productivity.

- Deli Serdang

  This district is located near Medan. The district shows a significant decrease in total productive areas since 2001. This district has several primary processors. Many district suppliers and village suppliers operate here. The rubber research centre is also located in this district. This district also produces good quality seeds for rubber replanting.

- Simalungun
  This district is located in the middle of North Sumatera Province. This district shows a stable trend in productive areas generated since 2001. This district is also a famous producer of high-quality rubber seeds.
- South Labuhan Batu
  This district is located at the south side of North Sumatera Province. The district is new, and is separated from Labuhan Batu District. This district shows a decreasing trend in productive area.

3.2.2 Data Collection Techniques

Certain data collection methods and data analysis methods are performed within the research process. However, not all data collection methods are required for use in research. As such, only some selected methods are needed. To define appropriate data collection methods, data requirement is a necessary consideration. These can be generated from research objectives. Table 3.2 provides connections between research objectives, data requirements, and data collection methods. The selected techniques are implemented sequentially, since exploratory mixed approaches are selected as the key research approach. The relationship between research processes and data collection techniques can be observed in Figure 3.3.

3.2.2.1 Interview

Interviewing comprises a process of collecting relevant information related to a given research problem by asking open questions to participants. During this process, participants are free to answer questions based on their opinions and points of view. The interviewer cannot direct participants to give a specific answer, but the interviewer can expand questions in order to encourage participants to provide more information.

In this research, the interview is used as one selected method to ascertain information and data related to Indonesia’s natural rubber industry, including the current conditions of industry, the natural rubber supply network, the key players in the natural rubber industry, the behaviour of key players, and other relevant information. This method is applied to extract information from practitioners, researchers, government officers, academics, and key players in Indonesia’s natural rubber industry. This also extends to rubber smallholders, village suppliers, district suppliers, and traders.

Interviews can be divided into open interviews, semi structured interviews, and structured interviews. In open interviews, the interviewer does not have a list of questions, but still has a focus and objective. Interviewers are free to initiate communications with participants. In semi-structured interviews, interviewers use lists of questions to build communications with participants, but are free to expand questions based on responses of participants. In structured interviews, the interviewer develops questions based on research problems, and focuses on developing questions during the interview process.

Research in this study uses semi-structured interviews to ascertain information from targeted participants. This technique is mainly applied in the qualitative phase and in the first stage of the research process (see Figure 3.3). Semi structured interviews are developed to find the answers to several questions, including:

- What are the current problems facing Indonesia's natural rubber industry?
- How do replanting decisions influence other entities and other key players in the supply network?
- How do replanting decisions influence the sustainability of natural rubber supply networks?
- Which sustainability dimension or indicator is influenced by replanting decisions?
- How do smallholders describe their decision to replant land?
- What factors influence smallholders' replanting decisions?
- What factors influence the suppliers in determining latex price?

The complete semi structured interview, including a summary of interview results which is produced by using thematic data analysis, can be observed in appendix A.

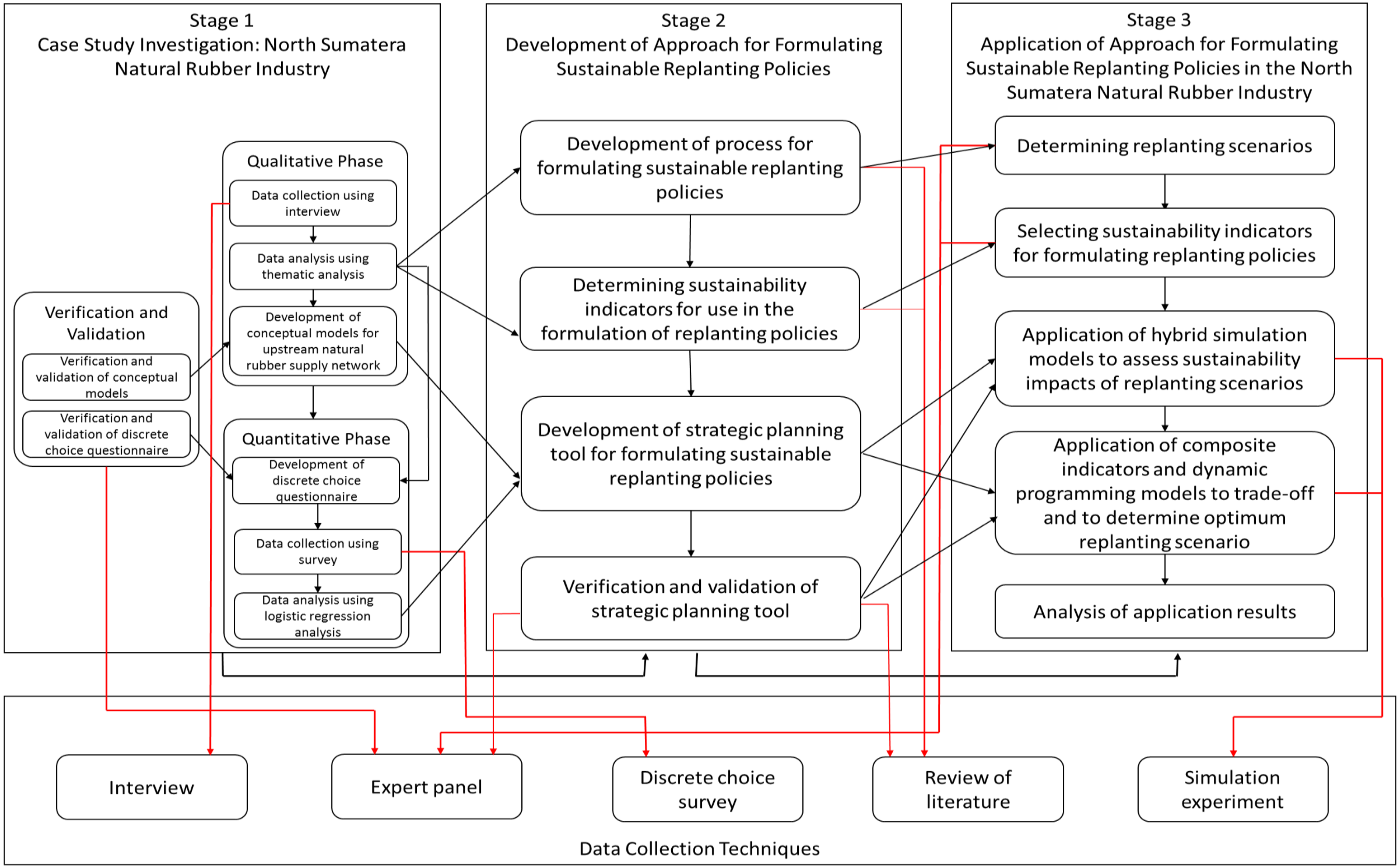

Figure 3.3 The Relationship between the Research Process and Data Collection Techniques

Table 3.2 Links between research objectives, data requirements, and research techniques

Research objectives	Type of data required	Data collection methods				
		Interview	Review of literature	Discrete choice survey	Simulation experiment	Expert panel
To identify approaches for developing sustainable supply networks	Different types of sustainability assessment tools		√			
	Different types of planning model in agriculture industry		√			
To develop a case study of Indonesia's upstream rubber supply network	Statistic data related North Sumatera natural rubber industry		√			
	Related stakeholders in North Sumatera natural rubber industry	√	√			
	Information related districts which have rubber plantations	√	√			
To identify requirements for formulating sustainable replanting policies in the Indonesian natural rubber industry supply network	Replanting impacts into economic, environmental and social	√	√			
To design and prototype an approach for formulating sustainable replanting policies	Entities and key players in Indonesia natural rubber industry	√	√	√		
	Relationship between entities in Indonesia natural rubber industry	√	√			
	Factors influence replanting decision	√	√	√		
	Indicator/ evaluation criteria for replanting	√	√			
	Behaviour of key players	√		√		
	Interaction between key players	√				
To verify the approach by using it with target users for formulating sustainable replanting policies in North Sumatera natural rubber industry supply network	Historical data		√			
	Understanding of Indonesia natural rubber system and supply network					√
	Scenario of simulation					√
	Setting of parameters		√			√
	Initial data		√			
	Simulation results				√	

3.2.2.2 Review of Literature

Reviewing literature comprises a process of exploring information and data. Literature used here can be categorised into journal papers, scientific reports, and government reports. The main purpose of this technique is to explore various tools that have been used by academics and researchers as sustainability assessments and planning models in the agricultural industry. Furthermore, literature such as statistical reports and government reports are essential sources of information for the current implementation of rubber replanting in Indonesia.

The process of reviewing literature is not only focused on documents, but also in researching documents with a related research problem. Government reports and statistical report may not be accessible online, and instead may require specific permissions from government offices or related government officers. The use of these type of data must therefore follow regulations imposed by related government officials. This technique is implemented to define secondary data to support the development, validation, and application of sustainable replanting planning tools.

3.2.2.3 Discrete Choice Survey

The purpose of discrete choice surveys is to determine significant factors influencing the decisions of key players in Indonesia's natural rubber supply network, as well as to develop utility functions for predicting those decisions. A discrete choices survey is an approach used to explore decisions of respondents against alternative choices. These decisions are influenced by several factors ascertained from an experimental design to observe impact on respondents' decisions. Each person's choices are influenced by several factors. These factors can be divided into two types: observable factors and unobservable factors. The presence of unobservable factors can influence people's decisions. These decisions cannot be modelled deterministically, but can be modelled stochastically. As a result, people's decisions can be predicted by gauging the probability of observable factors and unobservable factors (Train, 2002). The discrete choice approach can therefore predict people's decisions by taking into account observable factors and unobservable factors. This approach is applied in the quantitative phase for determining the significant factors influencing key players' decisions in the upstream natural rubber supply network (see Figure 3.3).

According to Train (2002), there are three main properties of discrete choices. The first properties comprise alternatives or options, which should be designed and should be mutually exclusive. This means that a decision-maker should only choose one of the alternatives. Secondly, all alternatives and options are exhaustive. This means alternatives should cover all possible alternatives available to the decision-maker. Thirdly, the total number of alternative must be finite. The discrete choice model has been widely used in the transportation field. For example, discrete choice models support transportation project analyses, from the selection of modes of transport desired by people, to the determining of transport routes that are convenient, to deciding the price of transport seen as acceptable (Louviere et al., 2000).

The binary choice model is a type of discrete choice model in which there are only two alternatives available for the decision maker. This type of model is implemented whereby decision-makers face two options in making a decision, e.g. “Yes or No”; “I will consider this option or I will not consider this option”. Binary logit formulae are easier to interpret using an example. In the example where there are two responses, yes and no, the Binary Logit model can be expressed as:

$$P_{yes} = \frac{e^{V_{yes}}}{e^{V_{yes}} + e^{V_{no}}} \qquad \textbf{3.1}$$

Vyes can be expressed linearly, with observable factors and individual characteristics of those who select the yes response. β is a scalar associated with K observable factors (X) and α is a scalar associated with M individual characteristic (Z).

$$V_{yes} = \sum_{k} \beta_k X_k + \sum_{m} \alpha_m Z_m \qquad \textbf{3.2}$$

The binary choice model is implemented in this research to gauge decisions of key players including rubber smallholders, village suppliers, and district suppliers. The reason for selecting this method is in its simplicity in implementation. Since the profiles of key players gauged in the qualitative phase are indicated to have low education levels and low incomes, a more complex choice model is likely to increase difficulties in the survey process. Another reason for selecting this model lies in the response of key players. For example, in the decision to replant, the anticipated answer from rubber smallholders is “yes, I will replant my land” or “No, I will not replant my land”. These responses align with the binary choice model.

According to Louviere et al (2000), there are six stages for conducting discrete choice experiments. The first stage is to define study objectives. This step clarifies the objective demanded by the researcher for the experiment. The second stage is to conduct the supporting qualitative study. This step is used to investigate which decision is needed for further investigation, as well as to generate possible factors that influence decisions. The third stage is the development of data collection instruments. Based on the results from the qualitative study, a data collection instrument is developed. The fourth stage is to define sample characteristics. This step is used to calculate the sample needed in the experiment. The fifth stage is to conduct the data collection. In this step, the participant is contacted and interviewed using the data collection instrument. The sixth stage is to conduct data analysis. This step is used to tabulate data and to analyse models resulting from data collection. The seventh stage is to conduct policy analysis. This step is used to analyse the impact of decision models on current policy.

The most important step in the discrete choice approach is the creation of combinations of influential factors, which reflect situations or conditions influencing decision-making processes. One approach towards creating combinations of influential factors is fractional factorial design (Louviere et al., 2000). Louviere et al. suggest that fractional factorial design can be achieved by selecting the effect of interest from the full factorial design. The authors make a list of fractional factorial designs based on the selected effects of interest. The complexity of design increases sequentially in the list below of fractional factorial design proposed by Louviere et al. (2000):

- The main effects only, while each effect is independent from other effects.
- Some or all main effects, while each effect is independent from other effects, plus unobserved two-way interactions while each effect is not independent from other effects
- Main effects, plus some two-way interactions while each effect is independent from other effects.
- Main effects, plus some or all-bilinear two-way interactions while each effect is independent from other effects.
- Main effects, plus all two-way interactions while each effect is independent from other effects.
- Main effects, plus two-way interactions plus some or all three-way interactions while each effect is independent from other effects.

In order to set up the experiment so it can ascertain the effects of interests (in the list above), Louviere et al (2000) propose different approaches, including:

- Main effects can only be ascertained by designing an experiment using an orthogonal main effects design.
- An orthogonal main effects design can be folded over to create another profile. This design protects the main effects and linear x linear two-way interactions are unobserved.
- If there are key attributes that form key two-way interactions, this interaction is used by combining each of the key interactions' level with the main effects design for other attributes. This model protects all interactions of key interactions with other attributes, while other main effects are not protected from unobserved.

Furthermore, unbalanced designs should be avoided. Unbalanced design relates to the total number of levels for every attribute or factor. Unbalanced design can be prevented by designing an equal number of levels for each attribute, or if the level is not equal to each other, the total level of attributes for each attribute should be multiples of another attribute's level. For example, if there are five attributes which consist of 3, 4, 3, 2, 4 levels, the design is unbalanced. To create a balanced design, three level attributes must be changed to two level attributes, or four level attributes (multiples of two level attribute).

Using the above approach, the questionnaire for the discrete choice survey was designed. These comprised three types of a questionnaire: a questionnaire for rubber smallholders for replanting decisions and making fertilizer decisions; and a questionnaire for village suppliers and district suppliers for pricing decisions. All questionnaires were designed by combining influential factors from the qualitative phase with their factor levels (see section 4.2). The orthogonal plan was applied to group influential factors into several conditions, which required answers by the participant. All discrete choice questionnaires can be observed in appendix B.

3.2.2.4 Simulation Experiment

A simulation experiment is an approach to conducting experiments in an artificial environment, which reflects the real system under examination. This approach is applied when experimentation in the real world is difficult to implement owing to cost and time. Experimentation means that important variables in the system under examination are modified and manipulated to produce different results.

In this research study, simulation experiments are applied to validate proposed tools and to support decision-making related to rubber replanting in the North Sumatera natural rubber industry. A simulation experiment is run using real data from selected districts in North Sumatra. The complete design of this simulation experiment can be observed in chapter six.

3.2.2.5 Expert Panel

An expert panel comprises a forum of experts that is formed to support research by giving information and feedback on related tools and research processes. This offers one method to validate the proposed model. The expert panel consists of a representative of rubber practitioners, a rubber researcher, and a relevant academic. In this research, an expert panel is invited to give feedback on the proposed model. Their experience about natural rubber system is used to examine the proposed model in terms of the behaviour of the model and its variables. The expert panel also provides information for the simulation experiment.

3.2.3 Participants

This study's research requires participants as a source of information. The participants are determined based on research approaches and the type of data required from participants. Participants in this research are divided into three types for the qualitative phase, quantitative phase, and participants who comprise the expert panel. The following sections describe the selection of participants.

3.2.3.1 Participants for qualitative phase

The purpose of the qualitative phase is to generate a depth of understanding about the Indonesia rubber supply network. This information is gained from related stakeholders and key players who have substantial experience in the natural rubber industry. As a result, key players and main stakeholders are necessary chosen participants. Participants in the qualitative phase are selected by using purposive sampling. According to Guarte and Barrios (2006), purposive sampling is applied to gather a sample of participants that has information on a specific point of interest from within the population. In this research, samples are ascertained by observing the ability of participants to offer information about current problems and issues relating to sustainability in the natural rubber supply network. The Qualitative phase was conducted between November – December 2015. Table 3.3 provides a summary of participants for the qualitative phase.

Table 3.3 Participants for Qualitative Phase

Type of Participant	Number of Participants	Length of Interview (Minutes)	Explanation
Government, province and district estate agency	2	33 for P1 92 for P2	P1 from North Sumatera Plantation Agency and P2 from Seed protection and certification agency
Association of rubber primary processors	2	75 for P3 70 for P4	P3 from Rubber Primary Association, P4 from Bakrie Plantation
Rubber research centre	2	107 for P5 78 for P6	P5 and P6 from Sungai Putih Rubber Research Centre
Smallholders	3	65 for P7 43 for P8 152 for P9	P8 and P9 are smallholders in Langkat District, P7 is smallholder in South Labuhan Batu District
Village collectors	2	30 for P10 25 for P11	P10 and P11 are village collectors in Langkat District
District suppliers	2	57 for P12 43 for P13	P12 is district supplier in South Labuhan Batu District P13 is district supplier in Langkat district
Rubber Traders	2	51 for P14 42 for P15	P14 and P15 are rubber traders from primary processors located in Deli Serdang District

P = Participant

3.2.3.2 Participants for Quantitative Phase

The objective of the quantitative phase is to investigate the factors affecting key players' decisions in the upstream natural rubber supply network. Key players in North Sumatera's upstream natural rubber supply network were therefore selected as participants. The quantitative phase used a discrete choice survey to identify significant factors influencing key players' decisions, such as the decisions around fertilizer, decisions around replanting, and decisions related to determining latex price. To determine the total number of participants required for this survey, the equation proposed by Louviere et al. (2000) was implemented. This equation is used to calculate the sample size by considering true proportion p, relative accuracy a, r choices of scenario (replications) and probability α (0.90, 0.95, 0.99).

$$n \geq \frac{q}{rpa^2} \emptyset^{-1} \frac{(1+\alpha)}{2} \tag{3}$$

Where $\emptyset^{-1}$ is inverse of the cumulative normal distribution function. Louviere et al., (2000) also provide a table of sample sizes using the above equation with relative accuracy a 10 % of p with a probability of 0.95.

Table 3.4 Sample size calculation (a=10%, Probability=0.95)(Louviere et al., 2000)

p	Number decision required	Number of respondent required (r =8)
0.1	3457	432
0.2	1537	192
0.3	896	112
0.4	576	72
0.5	384	48
0.6	256	32
0.7	165	21
0.8	96	12

Table 3.5 shows a number of participants for quantitative phase. Further detail relating to profile of participants in quantitative phase can be seen in section 4.2.

Table 3.5 Participant for quantitative phase

Type of Participants	Number of Participants	Total number of Decision Collected
Rubber smallholders	90	720 decisions for giving fertilizer 1008 decisions for replanting
Village Suppliers	31	456 decisions for determining latex price at village level
District Suppliers	36	448 decisions for determining latex price at district level

3.2.3.3 Expert Panel for Verification, Validation and Experimentation

An expert panel was configured in order to evaluate the conceptual models, the proposed tools, and to participate in experimentation regarding the tools' applications. In the qualitative phase, the expert panel participated in evaluating the conceptual models of the upstream natural rubber supply network. In the quantitative phase, the expert panel was assigned to verify and validate a discrete choice questionnaire. This was conducted in February 2016. The summary feedback of expert panel to inform the conceptual modelling and discrete choice questionnaires can be seen in section 4.1.3 and B.1.3.

In the second stage of research, the expert panel was arranged to evaluate the computerised models. At this stage, the expert panel compared the computerised models with conceptual models. Feedback from the panel was used to improve the tools. This was conducted on May 2016. The summary feedback of expert panel to inform the computerised modelling can be seen in section 5.4.

In the third stage of research, the expert panel was invited to participate in the application of strategic planning tool. The expert panel was involved in designing scenarios of replanting and in determining the setting of experiments for the application of tool. This was conducted through a workshop in July 2016. The results of the workshop include replanting scenarios, simulation parameters and weightings for sustainability indicators and dimensions, which can be seen in section 6.1, 6.2 and 6.4. By considering the importance of feedback from the expert panel, practitioners, researchers and academics, all of whom have wide-ranging experience in the natural rubber industry, participants were selected. Table 3.6 shows the participants recruited for the expert panel.

Table 3.6 Participants for Expert Panel

Type of Participant	Number of Participants	Time to meet	Explanation
Government Officer	2	1. In February 2016, for evaluating conceptual models and discrete choice questionnaire 2. In May 2016 for evaluating computerised model 3. In July 2016 for application of approach	Participants from North Sumatera Plantation agency
Association of Rubber Primary Processor	2		Participant from GAPKINDO
Rubber researcher and academics	2		Sungai Putih Centre and North Sumatera University

3.2.4 Ethical Requirement

The research in this study uses humans as participants, to give essential information and data related to the research problem. The University of Leeds has an ethical standard for research involving humans as objects of research, particularly around or participants from vulnerable groups, e.g. children under 16, adults with learning disabilities, and adults in emergencies. This standard of ethics must be followed by researchers. To maintain this standard, researchers are required to submit ethical documents to be reviewed by an ethical board at the university. Ethical documents consist of an ethical review form, an information sheet, a fieldwork assessment sheet, and an informed consent form.

The ethical review form comprises a document that consists of several questions related to how research is performed, who participants will be, how participants are recruited, what rights the participants maintain, the responsibilities of the researcher, and what is sought from the participant. All of these questions are asked to ensure that the research process follows the university’s ethical standard. The fieldwork assessment sheet is a document that consists of an explanation of related activities used in field work, including location of the fieldwork’s implementation, the conditions of the field work location, identifying any hazards that can threaten the researcher, and locating any specific physical requirement that the researcher must fulfil, e.g. vaccination or health surveillance.

The information sheet comprises a document that explains the overall research process to those that the research concerns. This document contains information related to the research, including its aim and objectives, reasons why participants are required for the research, and the rights of participants. This document is also equipped with an informed consent form. Participants are required to fill the informed consent form in, to ensure that participants have a good understanding of research, and rights within the research process, and that they are agreeing to freely participate in the research. Ethical approval from Joint Faculty Research Ethic Committee, University of Leeds, can be observed in the appendix G.

Chapter 4
Case Study: The North Sumatera Natural Rubber Industry Supply Network

The current condition of the natural rubber industry in the North Sumatera Province is a main driver in determining the aims and objectives of this study's research. North Sumatera was selected as a case study owing to its significant reduction in natural rubber supply. This has been caused by several factors, including climate change, the increasing of low-productive areas over the last ten years, and the phenomenon of crop-switching among rubber smallholders. The North Sumatera natural rubber industry consists of several key players, from rubber plantations and natural rubber suppliers to primary processors and downstream industries. This renders this particular industry a suitable representative of Indonesia's natural rubber industry.

North Sumatera Province is located on the north side of Sumatera Island and on the eastern side of Indonesia. North Sumatera Province has a tropical climate owing to its proximity to the equator. Parts of North Sumatera Province are characterised by flat surfaces that are a few metres above sea level, while others consist of hilly surfaces with gentle slopes, and some areas in the highlands. The temperature in North Sumatera Province varies between 21 C – 30 C with two types of season: rainy and dry. Such characteristics of the surface and climate in North Sumatera Province have helped the region to become a centre of plantation in Indonesia. Natural rubber is a popular plantation crop in this region, comprising a major industry that has had a significant impact on the economic landscape of the territory, by generating income for many people and for local governments.

Rubber plantations are scattered across 25 districts in this province. The largest area of rubber plantation is located in Mandailing Natal District with 72.159 Ha, while Karo is the smallest area of rubber plantation, with only 94 Ha. Accumulated latex from rubber plantations is processed by primary processors into work-in-process materials such as crumb rubber, rubber smoke sheet, and high-concentration latex. Primary processors are scattered across several districts, including Deli Serdang, Simalungun, Asahan and labuhan batu. Figure 4.1 shows a map of North Sumatera Province.

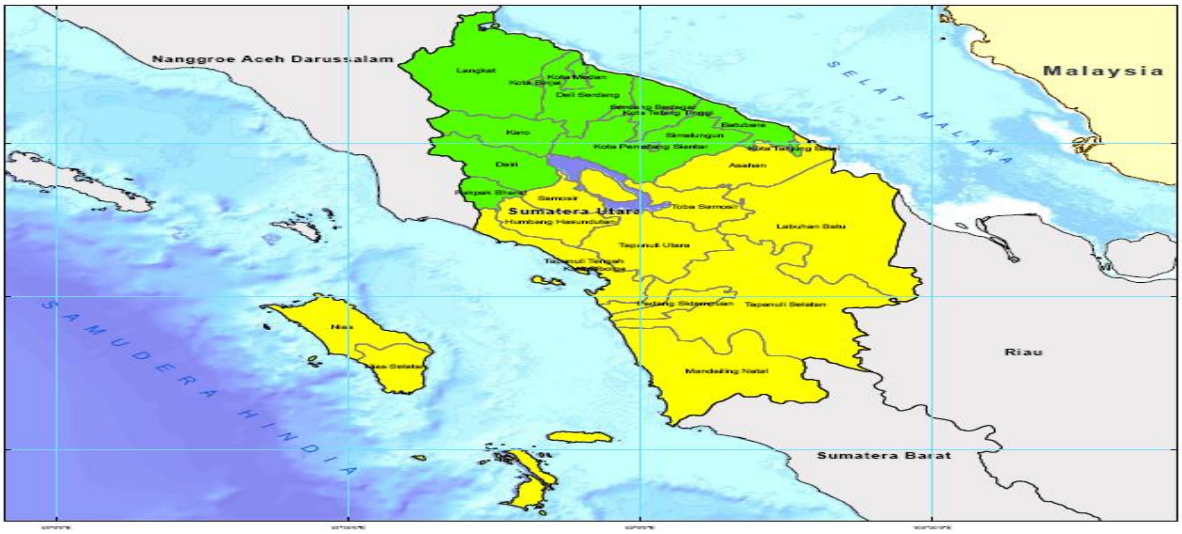

Figure 4.1 Map of North Sumatera Province (source: http://geospasial.bnpb.go.id)

This chapter introduces the configuration of Indonesia's upstream natural rubber supply network in North Sumatera Province, used here as a case study. This chapter reports the results of data collection and data analysis in the qualitative and quantitative phases at the first stage of the research process. In the qualitative phase, interviews were used to identify entities, and relationships between those entities, in the upstream natural rubber supply network, as well as to identify operations performed by key players. In the quantitative phase, discrete choice experiments were used to identify external factors influencing key players' decisions, as well as to model those decisions. Outcomes from the qualitative phase gave conceptual models of North Sumatera's upstream natural rubber supply network, while the quantitative phase configured decision models for key players in North Sumatera's upstream natural rubber supply network. Figure 4.2 shows the relationship between the research process and the case study chapter.

This chapter is divided into three main sections. The first, section 4.1, reports on the conceptual models of North Sumatera's natural rubber supply network. These conceptual models were produced from data analysis that was conducted using interviews in the qualitative phase. The conceptual models consist of two models, including natural rubber production and its distribution system (explained in section 4.1.1), and the structure of operations performed by key players in North Sumatera's upstream natural rubber supply network (reported in section 4.1.2). This is followed by section 4.2, which investigates external factors influencing key players' decisions. This section reports on the decision models of key players, which were produced from a logistic regression analysis of data that was collected using the discrete choice survey during the quantitative phase. Finally, section 4.5 presents a summary of the case study section.

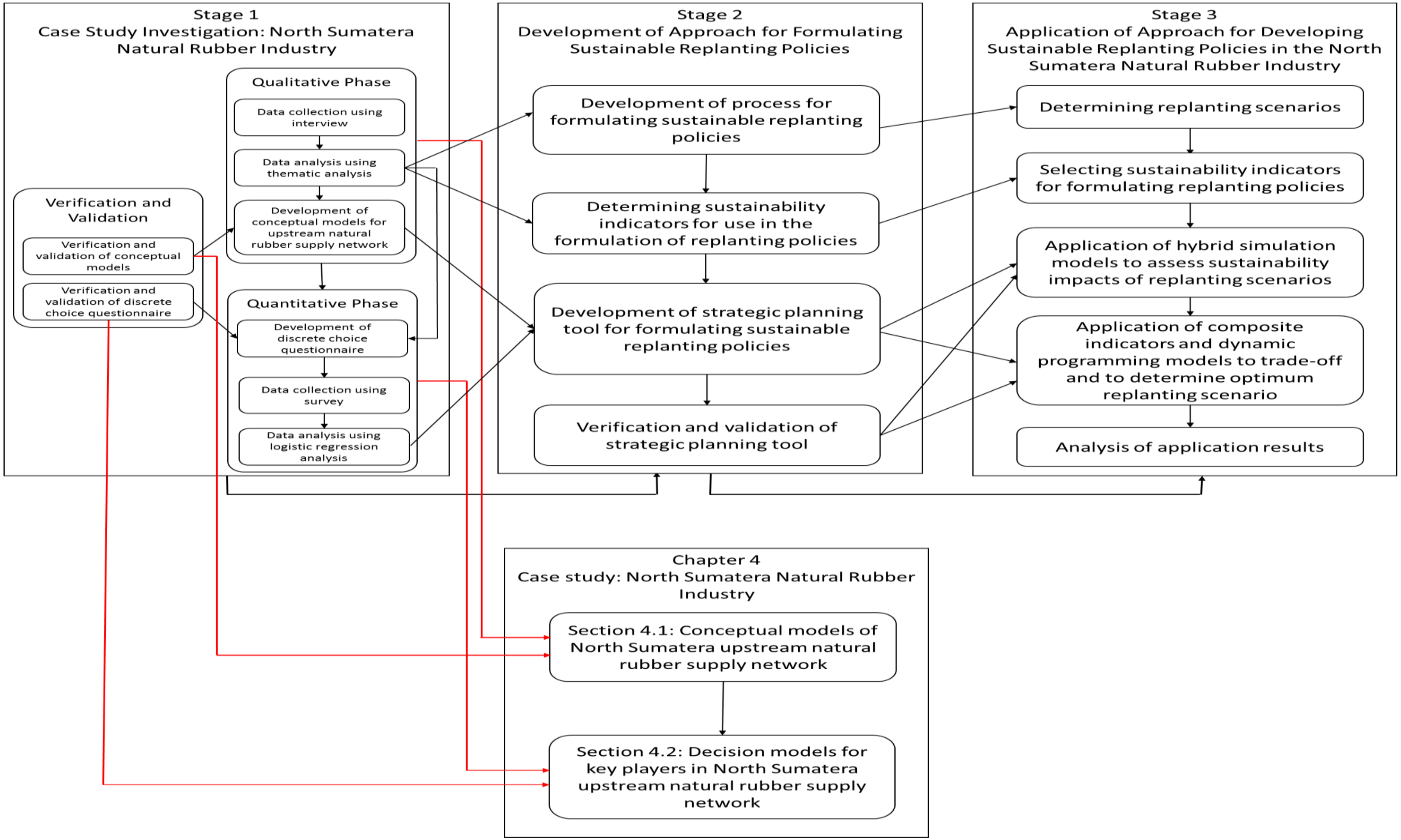

Figure 4.2 Links between the Research Process and Chapter 4

4.1 Conceptual Models of North Sumatera's Upstream Natural Rubber Supply Network

By using North Sumatera's natural rubber supply network as a case study, conceptual models can illustrate the Indonesian natural rubber production and distribution system, and can illuminate operations performed by key players. There are two conceptual models introduced in this section: natural rubber production and its distribution system, and the structure of the supply network and the operations of its key players'. The conceptual models given were constructed on the basis of data and information from stakeholders' and key players' interviews.

4.1.1 North Sumatera's Natural Rubber Production and Distribution System

The main purpose of this conceptual model is to illustrate the entities of Indonesian natural rubber production and its distribution system, as well as the relationships of those entities. This conceptual model was constructed using a causal-loop diagram based on information gathered from stakeholders and key players. Causal-loop diagram captures the entities of a targeted system using a circular symbol, and likewise captures the relationship between entities using an arrow symbol. The conceptual model used for Indonesia's natural rubber production and distribution system is divided into three sections, including the life cycle of plantations and land change, latex production, and latex distribution.

4.1.1.1 The Life cycle of Plantations and Land change

This section introduces a conceptual model of rubber plantations' life cycles in North Sumatera Province. This section is designed to gauge changes in the composition of immature, productive, and low-productive areas caused by the life cycle of rubber plantations. Based on information from interviews, rubber smallholders in Indonesia and North Sumatera currently utilize their plantations for 30 years, or in other words, for one cycle, as plantations operate for 30 years before replanting. The main variables in this section are the plantation area, the total replanting carried out by smallholders, the new plantations created by smallholders, the population of rubber smallholders, and the proportion smallholders switching crops. Plantation areas are divided into three types, including immature plantations, productive plantations, and low-productive plantations. Immature plantations comprise plantation areas that get new rubber plants from planting new plantations and replanting for low-productive plantations. Figure 4.3 shows the variables and parameters in the life cycle of rubber plantations.

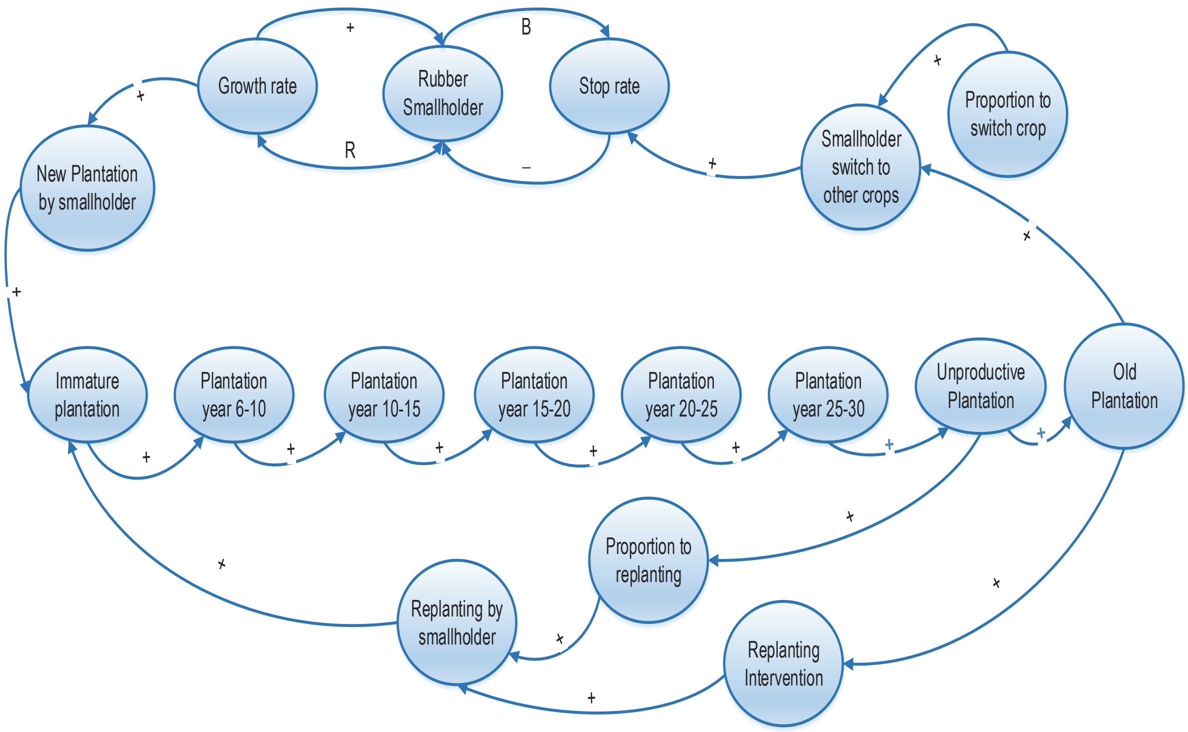

Figure 4.3 The Life Cycle of Rubber plantations and Land Change System

Rubber trees at immature plantations vary in age between 0 to 6 years. Productive plantations in North Sumatera can be divided into 5 phases, including plantations of 6-10 years, plantations of 10-15 years, plantations of 15-20 years, plantations of 20-25 years, and plantations of 25-30 years. This categorization is employed owing to the different productivity levels at each phase. Rubber plants are expected to achieve their highest productivity in phase 2 and phase 3. After this phase, production remains stable at phase 4, and starts to decrease at phase 5. Low-productive areas consist of two types, including unproductive plantations and old plantations. Unproductive plantations are plantation areas that at are around an age of more than 30 years. At this stage, rubber smallholders generally make the decision to replant their land. Old plantations are plantation areas within which owners have decided not to replant. A combination of these variables presents the life cycle of rubber plantations. Dynamic change in the composition of plantation areas within the network can thus be captured through analysing these variables.

The composition of rubber plantation areas is affected by three variables, including the availability of new plantations, the total replanting carried out by smallholders, and the total occurrence of crop switching. The availability of new plantations refers to new rubber plantations that have been opened by new smallholders. New plantations increase the total area of immature production. The total replanting carried out by smallholders is given by rubber smallholders that have decided to replant their land while entering a low-productive phase and by replanting interventions. The decision of smallholders to replant their land is reflected in the proportion replanting. Not all smallholders with low-productive plantations will decide to replant their plantation. Replanting interventions comprise forms of intervention taken by stakeholders to change old plantations into immature areas. This is a part of the government's programme to rehabilitate old plantations in order to sustain the natural rubber supply.

The last variable influencing the composition of rubber plantations is the total number of crop switching carried out. This variable refers to smallholders that have low-productive plantations, who subsequently decide to switch crops within their plantations. The main reason behind switching crops is the latex price. If latex price decreases, rubber smallholders consider rubber plantations to be unprofitable. Hence, smallholders try to find other crops that are more profitable. This pushes land changes in rubber plantation areas while rubber is replaced by other crops like palm oil, cocoa, and corn. Rubber smallholders' population is also a variable that is affected by land changes in plantation areas. Additional plantation areas brought by new plantations contribute to increases in the population of rubber smallholders, while decisions to switch crops among smallholders diminish the population of rubber smallholders.

4.1.1.2 Latex Production

This section presents a conceptual model of the latex production system. Latex is produced from rubber trees in plantations by implementing a tapping process to the skin of rubber trees. Those conducting this process are known as tappers. Rubber trees are tapped every two days by tappers. Latex production is therefore influenced, naturally, by the total productive area and the availability of tappers' labor.

To comprehensively understand the latex production system, several variables are introduced to represent related entities in the system, including the population of tappers, the total productive area, the production rate, fertilizer use, and herbicide use. The population of the tappers comprises the total number of tappers operating at a district level. The dynamics of this population changes according to the total productive area, since immature areas cannot be tapped. To illustrate this change, variables including the covering area, the demands for new tappers, and reductions in current tappers are presented. The covering area reflects the total productive area that can be tapped by the existing population of tapper. The covering area is calculated by multiplying the total population of tappers with the average covering area per tapper. Generally, every tapper can tap 1-1.5 Hectares of a rubber plantation area per day. Variables relating to demands for new tapper and reduction in existing tappers are counted by dividing the total productive area with the area covered by tappers. Regarding the reduction of the current tapper labour force, if the area covered is exceeds the total productive area, the current population of tappers needs to be reduced. On the contrary, as regards the demand for new tappers, if the current population of tappers cannot cover the total productive area, or if the area covered is smaller than the total productive area, the system requires new tappers.

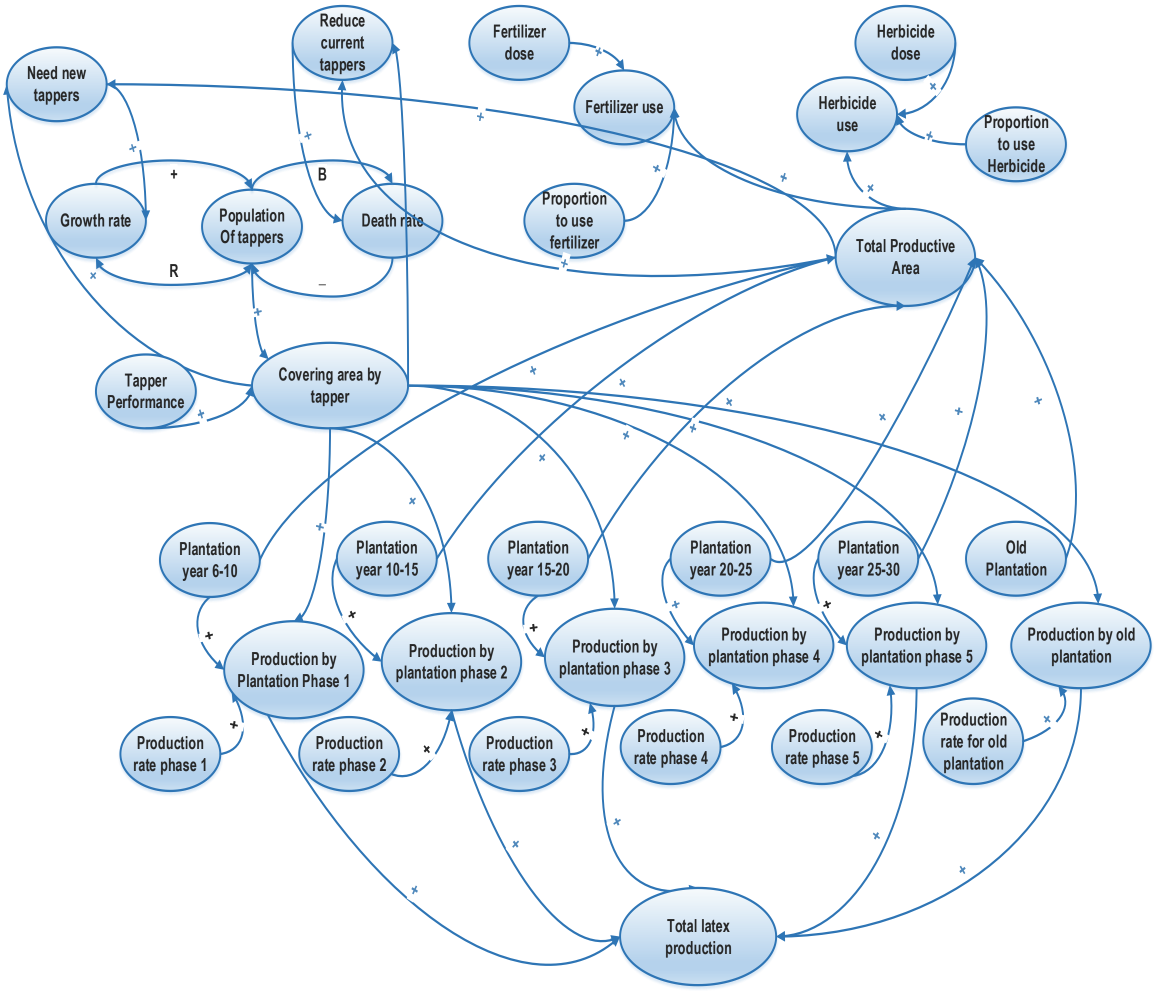

Figure 4.4 Latex Production system

To determine latex production, the total productive area covered by the tapper is multiplied by the production rate. Every phase in the productive area has a potentially different production rate owing to the different ages of plantations. For example, the production rate for phase 1 of plantation (6-10 years) is below the production rate for phase 3 (15-20 years). The production rate is furthermore influenced by the location of plantations. Each district has a potentially different production rate owing to different weather conditions and types of rubber clone.

Using production rate variables for every phase can illustrate adjustments in the production of latex based on the real conditions of rubber plantations. Total latex production is calculated by adding up the production of each phase. Over time, total latex production is changed according to transformations in the composition of rubber plantations.

Other important variables in latex production incorporate fertilizer use and herbicide use. Fertilizer use refers to the total amount of fertilizer applied by rubber smallholders to their plantations. Implementation of fertilizer is necessary to ensure that soil or land has enough nutrients for rubber tree growth. However, not all rubber smallholders apply fertilizer to their plantations. Ascertaining proportions of fertilizer use is introduced here to gauge this. The proportion is multiplied by fertilizer dose to acquire the total fertilizer use. Herbicide is applied to remove unnecessary plants that grow between rubber trees. However, not all rubber smallholders apply herbicide; some of them remove unnecessary plants manually without employing any chemical substances. This process is illuminated by introducing proportions of herbicide use to the model. The total herbicide use in one district is counted by multiplying the proportion of herbicide use with the herbicide dose. Implementation of fertilizer and herbicide are two of the biggest contributors of greenhouse gas emissions in rubber plantations. Complete parameters and variables for latex production system are given in Figure 4.4.

4.1.1.3 Latex Distribution

This section introduces a conceptual model of the latex distribution system, which captures the flow of latex from rubber plantations to primary processors. Based on information from interviews, three types of supplier are involved in delivering latex to primary processors, including village suppliers, district suppliers, and traders. The population of these suppliers is therefore a critical factor in delivering latex. To understand the latex distribution system, several variables and parameters are delineated in Figure 4.5.

After a rubber tree has been tapped, latex starts to flow into container shelters or cups. After a few hours, tappers will collect latex from every cup in every tree of the plantation. This latex is then coagulated before it is sold to suppliers. Based on its shape, there are three types of coagulated latex produced by rubber smallholders: lumps, slabs, and sheets. The majority of smallholders produce lumps, but in some villages, there are several rubber smallholders that produce slabs and sheets. To illuminate this, the proportions of lumps, slabs, and sheets produced are ascertained and used. These proportions are multiplied with the total latex production in order to determine lump, slab, and sheet production.

This coagulated latex is subsequently supplied by village suppliers. The population of village suppliers and the average capacity of village suppliers both influence the total coagulated latex they supply. Total latex production is nonetheless also impacted by the composition of plantation areas. Changes in latex production affect the population of village suppliers. Reductions in latex production also decrease the population of village suppliers. An increase in latex production, conversely, will increase the amount of village suppliers. To gauge this, we need to consider variables including demand for new village suppliers and reductions in existing village suppliers. These variables are defined by comparing the total latex production with the total latex supplied by village suppliers. Demands for new village suppliers are ascertained when the total latex production is bigger than the total latex supplied. Conversely, if the total latex production is smaller than the total latex supplied, it can be concluded that the existing surplus population of village suppliers needs to be reduced. A similar approach can implemented for district suppliers and traders. The population of district suppliers is mainly affected by the total supply of village suppliers, and the population of traders is influenced by the total supply by district suppliers. The populations of these suppliers are thus indirectly changed through transformations in latex production. The dynamics of latex production and its effect on the population of suppliers is presented in Figure 4.5.

Another important variable in the latex distribution system is the utilization of primary processors. This variable reflects the comparison between the total coagulated latex received by primary processors and the average capacity of primary processors. The primary processor comprises one fundamental player that is impacted by natural rubber reductions, in that processors must subsequently reduce factory use. Currently, every district delivers latex supplies to several primary processors who are located nearby.

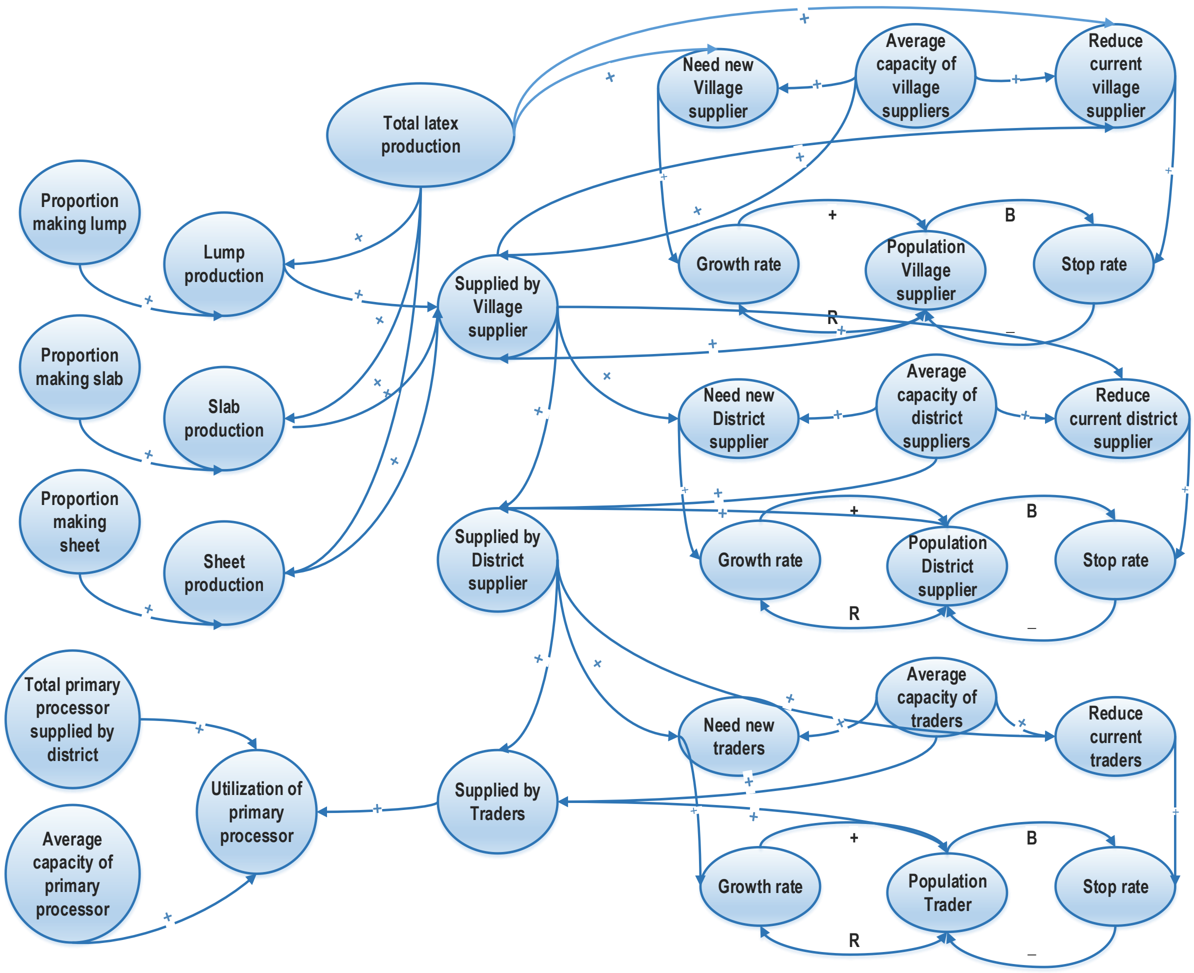

Figure 4.5 Latex Distribution System

4.1.2 Structure of Operations in the North Sumatera's Upstream Natural Rubber Supply Network

This section outlines the operations performed by key players in North Sumatera's upstream natural rubber supply network. These operations are identified by interviewing several agents from different stages in North Sumatera's upstream natural rubber supply network. Based on the geographical condition and the hierarchy of the Indonesian government, Indonesia's natural rubber supply network can be divided into three levels, incorporating province level, district level, and sub-district or village level. The majority of rubber smallholders are scattered in the village, which comprises the lowest level of Indonesia's natural rubber supply network. Contrastingly, the majority of primary processors are located at the district capital or the province capital. As a result, the rubber supply flows through several stages before reaching the primary processor. Figure 4.6 shows the different stages in North Sumatera's upstream natural rubber supply network.

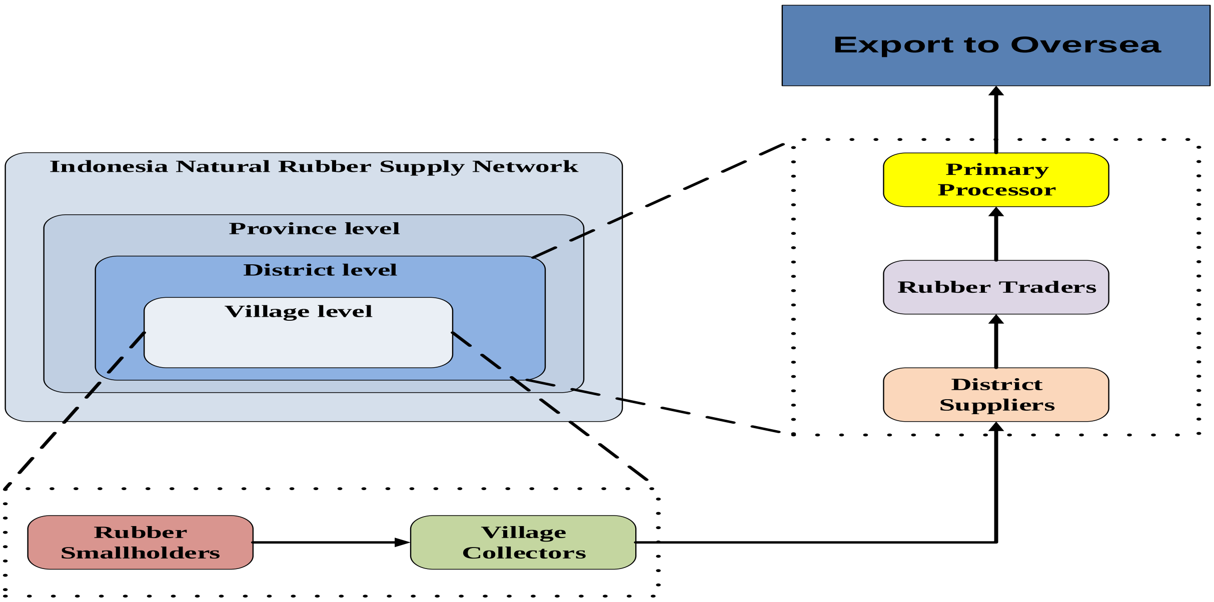

Figure 4.6 North Sumatera Upstream Natural Rubber Supply Network

The natural rubber supply is ascertained at the village level by village suppliers. These stocks, together with other stocks from different villages, are collected by district suppliers. After reaching the maximum capacity at district supplier level, natural rubber is sent directly to primary processors. Rubber traders, which are representative of primary processors, accept rubber coming from different district suppliers, at different locations. The combination of rubber smallholders, village suppliers, district suppliers, rubber traders, and primary processors configure the upstream natural rubber supply network in North Sumatera.

4.1.2.1 Rubber Smallholders' Operations

Rubber smallholders manage their rubber plantations by conducting several activities, including cultivation, latex processing, the selling of latex, and performing decision-making which affects by several external factors. This section discusses the activities and decision-making processes of rubber smallholders. Information on these processes has been gained through interviewing several rubber smallholders. Table 4.1 summarises the activities and decision-making processes that are implemented by rubber smallholders.

Rubber smallholders in the North Sumatera Province can be divided into two categories: 1) those who perform all activities, including land cultivation, tapping rubber trees, and selling latex themselves, 2) those who own the land, with cultivation, tapping, and selling activities being performed by employees. The first type of rubber smallholder usually owns a small area of a plantation – often less than two hectares – while the second type of rubber smallholder owns a bigger area of the plantation, which usually spans more than 2 hectares.

Table 4.1 Rubber Smallholder Activities, Decisions, and Factors Influencing Decisions

Type of Player	**Characteristic**	**Explanation**
Rubber Small-holder	Activities	• Cultivating plantation; this activity consists of two activities: clearing the plantation of unwanted plants, and applying fertilizer • Producing latex; this activity consists of tapping rubber trees, and coagulating accumulated latex • Selling Latex; after accumulating latex for one week, the smallholder is ready to sell it. Rubber smallholders will contact village collectors communicating price. If an agreement about the latex price is achieved, village collector will come to the plantation and collect latex. • Replanting; this activity is applied after plantation enters its low-productive phase (after 30 Years); rubber smallholder will replant their plantations with new rubber tree.
	Position	Rubber smallholder is located in village
	Decisions	• Applying fertilizer to their plantation; this decision is influenced by the selling price of latex, fertilizer price, availability of fertilizer, and impact of fertilizer • Determining Supply channel; there are two alternatives – via village suppliers or directly to district supplier. Rubber smallholders will sell their latex to village supplier/district supplier who offer the highest price and who maintain good relations with them. Only rubber smallholders that produce more than 1000 Kg per week can sell their latex directly to district suppliers. • Conducting replanting; many factors influence this type of decision: the selling price of latex, the price of alternative crops, replanting cost, availability of seed, price of rubber seed, price of rubber wood, availability of government aid and skill to replant
	Technical Specifications of rubber smallholders	• Rubber smallholder has square of area around 2-10 Ha • Produces lump, sheet or slab as product of plantation • Productivity is around 900 Kg Latex/ year depending on the cultivation technique implemented by rubber smallholders

Both types of rubber smallholder have different ways of managing their plantations. The first type of rubber smallholder tends to cultivate their land less effectively than the second type of rubber smallholder. As a result, the productivity of the first category of rubber plantations tends to be smaller than the second type. This can be observed in the way that the first type cultivates their land. In clearing the land of unwanted plants, for example, the first category is more likely to require a longer time, because they must clear the land manually and only rely on their own labour. Moreover, for rubber smallholders at older ages, the ability to effectively manage their land is significantly reduced.

The second type of rubber smallholder moreover tends to hire an employee for the cultivation of land and rubber tree tapping. Usually, this employee is selected from people who live in the same village, or in different villages in close proximity to the rubber plantation. Employee selection is based on cultivation skills and levels of payment. The majority of employees are paid based on a share in the percentage of the product sold. This percentage is agreed by rubber smallholders and employees before the work is started. A normal total of the percentage comes to around 30-60%, depending on the location of the rubber plantation. The percentage shared is calculated after subtracting cultivation costs, including fertilizer cost and chemical cost, from sales income. An impact of sharing income is naturally that smallholder income per hectare for the second smallholder category is less than the income per hectare of the first type.

Fertilizer is one factor that influences the productivity of plantations, in its provision of enough nutrients for rubber trees. The decisions of rubber smallholders to use fertilizer in their plantations is influenced by several factors, including the price of fertilizer, the latex price, the availability of fertilizer, and the impact of fertilizer. Many rubber smallholders will not apply fertilizer if the latex price is at a low level. Moreover, in many areas, fertilizer is not available at all times. As a consequence, fertilizer is sometimes not available when rubber smallholders require it. Some rubber smallholders do not apply fertilizer because of the perception that fertilizer has a low impact in the plantation. According to these smallholders, fertilizer does not have any impact on latex production.

For the production of latex, rubber smallholders usually tap their rubber trees every two days or every day, if they divide their land into two zones (for example zone A and zone B, with zone A tapped on Monday and zone B tapped on Tuesday). Rubber trees in plantations should be tapped at the most convenient tapping time, which is generally from 1800 to 2200 PM. If employees or owners cannot finish all the areas of plantation within this interval time, then daily tapping methods are recommended by dividing rubber plantations into two zones. After tapping rubber trees, latex starts to flow from the trees and is accumulated in a cup that is tied to them. Latex is collected from the cup after 3 to 4 hours. Based on this description, it can be concluded that the decisions of rubber smallholders to tap their land is based on the area of plantations and the processing times of tapping activities.

The majority of rubber smallholders produce coagulated latex with different shapes, incorporating lumps, slabs, and sheets. Only small rubber smallholders produce less concentrated latex (fluid) owing to the limited numbers of primary processors that process less concentrated latex. The majority of rubber smallholders produce latex in lump form, which comprises coagulated latex in cups. A small portion of rubber smallholders produce a slab, which is latex that has coagulated in a square/ block shape. Only a small portion of rubber smallholders produce sheets, which is latex that is coagulated in a block shape and is subsequently rolled into a sheet to reduce water content. The decisions of rubber smallholders around types of latex produced are influenced by the habits of rubber smallholders in a given area. Furthermore, the availability of training for latex processing influences the ways rubber smallholders process latex. Nevertheless, there are no stringent rules outlined by primary processors with regard to the shape of coagulant latex.

The main problem in latex processing is related to the behaviour of many rubber smallholders using non-standard coagulant. As a result of this, coagulated latex has a low quality, which in turn reduces its price. The decision of rubber smallholders to use non-standard coagulant is influenced by the price and availability of standard coagulant in their given areas. In some districts, standard coagulant is rare. Low latex prices have furthermore affected the ability of rubber smallholders to buy standard coagulant. Primary processors also do not push rubber smallholders to use standard coagulant, and still accept coagulated latex that is produced using non-standard coagulant.

In selling their product, rubber smallholders have different routes, including through village suppliers or directly through district suppliers. The decision of rubber smallholders to sell their product is influenced by the location of plantations and the total production of latex. Rubber smallholders in mountainous or hilly locations usually use village suppliers owing to difficulties in access to the plantation. Rubber smallholders with big plantations areas and production levels of more than 1000 Kg per week usually contact district supplier directly. If there is more than one village supplier or district supplier operating in that village, rubber smallholders can choose suppliers that offer the highest price. However, this does not always occur, as some rubber smallholders choose suppliers based on existing relationships. In specific districts where the primary processor is located near to the rubber plantation, as in Simalungun, rubber smallholders directly supply latex via the district supplier. In this district, the village supplier is obsolete because of the proximity of the plantation to the primary processor.

The final activity of rubber smallholders is to replant their land when their plantations enter a low-productive phase (usually after 30 years). This decision influences the future rubber supply by introducing a new cycle to the low-productive area. Currently, many stakeholders in the North Sumatera natural rubber supply network exhibit an unwillingness to replant their land. This is expected to be one of the main factors in the reduction of rubber supply in the North Sumatera Province. In fact, it has been found that many factors influence the decisions of rubber smallholder to replant their land, including latex price, other commodity prices, replanting costs, and skills required for replanting. Rubber smallholders are unsatisfied with low rubber prices because income from rubber plantations no longer covers expenditures. As a result, they have started to compare rubber's profitability with that of crops widely planted in the same area. For example, in the North Sumatera province, palm oil is a popular crop as well as rubber. Rubber smallholders also have to consider rubber-replanting costs while making decisions about replanting, particularly given their limited funding. Rubber smallholders are also naturally concerned with the success of replanting. This is owing to the probability fungus attacking new rubber plants after replanting. This problem is nonetheless generally caused by conducting non-standard replanting, and rubber smallholders' ignorance around protective technology.

Several stakeholders in the North Sumatera natural rubber industry furthermore indicate that the availability of rubber seed and rubber seed prices can affect decisions to replant. Rubber smallholders who have the desire to replant their land face challenges in allocating recommended rubber seed. This is caused by small numbers of certified rubber seed producers being available in this area.

Evidence from associations of rubber primary processors indicates that replanting aid could help rubber smallholders to replant their land. This is based on experience around providing seed aid for numerous rubber smallholders in the North Sumatera Province. In this case, all stakeholders including the government should actively provide replanting aid to sustain rubber supplies. Furthermore, rubber primary associations indicate that rubber wood can be sold to provide funding for rubber replanting. Nonetheless, not all districts in North Sumatera have wood manufacturing capabilities. As a result, the rubber wood price could vary across different locations and districts; in some districts, rubber wood may indeed have no price.

4.1.2.2 Village Suppliers' Operations

The village supplier occupies a channel for supplying latex from rubber smallholders to district suppliers. The main function of village suppliers is to accumulate latex from different rubber smallholders and to supply it to the district supplier. This section outlines the activities and decision-making performed by the village supplier. Table 4.2 conveys this.

Table 4.2 Village Supplier Activities, Decisions, and Factors Influencing Decisions

Type of Player	Characteristic	Explanation
Village Supplier	Activities	• Contacting rubber smallholders to ask about their latex at certain times during the week, e.g. on Saturday or Sunday, usually after rubber smallholders finish tapping their plantations • Offering prices for latex to rubber smallholders • If rubber smallholders agree with the price, village suppliers will visit plantations and collect latex with motorcycle • Contacting district supplier to offer latex, if village supplier agrees with latex price, district supplier will collect latex from village supplier
	Position	Village supplier is located in village
	Decisions	• Determining latex price for rubber smallholder. There are many factors influencing decisions to determine latex price, e.g. latex price at primary processor, quality of latex, quantity of latex, transportation cost, distance to the plantation, number of rivals, and profit desired. • Determining district supplier who will buy latex, choosing nearest district supplier available. District supplier who offers best price will be selected
	Technical Specifications of village supplier	• Village supplier accumulates latex of around 500Kg – 1000Kg per week • Uses motorcycle to bring latex from plantation to their home with capacity of around 50 Kg – 100 Kg/ trip • Area covered is limited to one village and up to radius of 20 Km

Each village usually has one to ten village suppliers, depending on the total number of rubber suppliers in that area. Some village suppliers are also member of district suppliers. This means that village suppliers work for district suppliers to find latex supplies. District suppliers provide funding for their village supplier members to buy latex from rubber smallholders. Contrastingly, some village suppliers work independently and do not have any sort of special relationship with district suppliers.

As a result, these village suppliers can offer latex to many district suppliers and strike deals with district suppliers who offer the best price. However, independent village suppliers do not have strong funding support to buy latex, while village suppliers that are members of district suppliers are able to ask district suppliers for funding.

Village suppliers' operating times can vary between villages owing to the different tapping times of rubber smallholders. Usually, they operate two or three times a week. Village suppliers generally accumulate latex from 11 am to 5 pm. Suppliers must wait until rubber smallholders complete latex production in their plantations. Village suppliers generally cover a radius of 10 Km and are limited to one village where the village supplier lives. Village suppliers who pick up latex from rubber plantations usually use motorcycles as a mode of transportation. The capacities of these motorcycles are around 50 – 100 Kg for each collection process. Owing to funding limitations, and the number of village suppliers operating in each, village, together with transport capacities, the capacity of village suppliers in supplying latex is generally around 500 – 1000 Kg per week.

The most important decision made village suppliers around determining latex price. This decision influences the income of rubber smallholders and village suppliers. It has been found that in North Sumatera Province, village suppliers determine the price of latex based on several factors, including the latex price at the primary processor, the quality of latex, the quantity of latex, the distance of the plantation, profit per kilogram, and the number of competitors. Primary processors convey the latex price to rubber traders on a daily basis, and this information is then streamed to the district supplier, village supplier, and rubber smallholder. This price is used as the basis for village suppliers in determining latex price.

4.1.2.3 District Suppliers' Operations

District suppliers provide a supply channel for latex from the district level to primary processors. The main function of the district supplier is to collect latex from several village suppliers in different villages within one district, and then to send it to the primary processor. This section outlines the activities and decision-making processes performed by district suppliers. The activities and decisions made by district suppliers can be observed in Table 4.3.

District suppliers collect latex by sending trucks to pick up latex from village suppliers. During the pick-up process, latex is weighed to measure its quantity and quality, and village suppliers are paid based on the agreed price that day. The operating time of district suppliers can vary day by day. Due to different selling times in several villages, district suppliers send their trucks to villages according to the selling time in each village. Before sending truck, district suppliers have usually reached an agreement with some village suppliers to adjust the quantity of latex that will be picked up so that it does not exceed the truck's maximum capacity. Latex stocks are sent directly to the primary processor on the same day. District suppliers usually use trucks with a 5 – 10 tonne capacity. The capacity of district suppliers can subsequently be calculated based on the total number of trucks and the frequency with which trucks are sent to primary processors. This comes to around 5- 50 tonnes per week. The area covered by district suppliers can reach a radius of 200 km, which covers up to two neighbouring districts

Table 4.3 District Supplier Activities, Decisions, and Factors Influencing Decisions

Type of Player	**Characteristic**	**Explanation**
District Supplier	Activities	• Finding latex from villages and other districts by contacting village suppliers • Offering a price to village suppliers and, if village suppliers agree with the price, district suppliers will come to the village to collect latex • After collecting latex from different villages and reaching the maximum capacity of trucks, latex will be directly sent to primary processors • Contacting rubber traders and offering latex stocks. If the price is agreed by district supplier and rubber trader, latex stock is sent to primary processor
	Position	District supplier is located in the capital of district
	Decisions	• Determining the price of latex for village supplier. Factors that influence this price include latex price at the primary processor, quantity of latex offered by village supplier, quality of latex offered by village supplier, distance from plantation to primary processor, transportation cost, number of competitors, availability of latex, and profit desired • Determining primary processor as the destination for latex. District supplier will choose the primary processor that is nearest
	Technical Specifications of district supplier	• Average amount of latex supplied is around 5-50 tonnes • Uses truck with 5-10 tonne capacity • Operates daily, 7 days a week • Area covered by district supplier is up to two neighbouring districts with radius of around 200 Km

District suppliers supply latex to the primary processor nearest to their operating districts. However, if the nearest primary processor is no longer accepting latex – owing to over-capacity or if the latex price offered by the nearest primary processor is lower than other primary processors – district suppliers will seek alternative primary processors with better prices.

There are two types of district suppliers. The first type is a member of the rubber trader. Their funding for purchasing latex is supported by rubber traders. As a result, this type of district supplier must supply their latex stock to certain rubber traders. The second type of district supplier is independent and free to choose the destination of their stock. The first type of district supplier has a more reliable funding source compared with independent district suppliers.

District suppliers have to decide latex price for village suppliers. This price is determined on a daily basis. District suppliers determine the price of latex based on the latex price at the primary processor. This basic price is then influenced by the quality of latex offered by village suppliers, operational costs, the quantity of latex offered by village suppliers, the proximity of the primary processor, the number of competitors, and profit desired. Latex price can subsequently vary across different village suppliers.

4.1.2.4 Rubber Traders' Operations

Rubber traders function as representatives of primary processors for finding latex supplies from different districts and sometimes from other provinces. Each primary processor usually has 5 to 10 rubber traders. A main reason behind primary processors employing rubber traders is the control of latex supply, in terms of quantity and quality. This section outlines the activities and decision-making processes conducted by rubber traders. Table 4.4 summarises the activities and decisions-making processes undertaken by rubber traders.

Rubber traders are assigned by primary processors to find certain amounts of latex. As a result, rubber traders establish communications with different district suppliers to ascertain latex supply. Some rubber traders create district supplier as their members at district level. Traders support funding for their members to buy latex at district level. They also offer prices to other district suppliers who are not their members.

The main function of rubber traders is to find latex from district suppliers and to receive latex supply at the primary processor. Rubber traders, or their representatives, take on a position in primary processor to receive latex or trucks of latex sent by district suppliers. This accumulated latex can arrive at primary processors at any time during the week. After arriving at the primary processor, the stock is weighed and checked by primary processors. Levels of dry rubber content for every stock received from rubber traders is examined at the primary processor's laboratory. Results are announced to rubber traders and used as a basis for payment to rubber traders. The latex supply is paid based on current latex price levels, and the level of dry rubber content.

Table 4.4 Rubber Trader Activities, Decisions, and Factors Influencing Decisions

Type of Player	Characteristic	Explanation
Rubber Trader	Activities	• Contacting district suppliers and offering latex prices to district suppliers • Receiving latex from district suppliers, which comes from different districts • Overseeing the process of latex accumulation. This process consists of weighing the quantity of latex, measuring the dry content of latex, and checking the quality of latex • Paying for the amount of latex that is accumulated by each district supplier • Receiving payment from primary processors for latex
	Position	Rubber trader is located at the primary processor level
	Decisions	• Determining latex price by deducting latex price at primary processor with rubber trader fee and operational cost.
	Technical Specifications of rubber trader	• Rubber trader has the ability to accumulate latex at around 50 – 100 tonnes per week • Every primary processor has more than one rubber trader • Working every day and standing by at primary processor to accept latex • Area covered by rubber trader is province level

There are two types of rubber trader. The first type is rubber traders that sign a contract with primary processors to supply specific amounts of latex each month. The second type is rubber traders that only have the authority to supply latex to primary processors and do not sign any contract with primary processors. As a result, this type of rubber trader has more flexibility in terms of the amount of latex they can supply. The first type of rubber trader can usually fix a special price for their supply because they have set target quantities to supply each month.

Rubber traders determine the basis of latex price for district suppliers based on the latex price at primary processors and the dry rubber content of latex supplies. This basic price is reduced by rubber trader fees and operational costs, which come to around IDR 200 – IDR 300 per kg of latex. Rubber trader fees are the same for all district suppliers who supply latex via traders, according to different quantities. Rubber traders do not cover transportation costs because latex supply is received and dealt with by primary processors.

4.1.3 Validating Conceptual Models

Conceptual models need to be verified and validated in order to ensure that all necessary entities and relationships are gauged by conceptual models. An expert panel was assigned to conduct this verification and validation of conceptual models. The expert panel consisted of practitioners, academics, and researchers who have been involved in the natural rubber industry for more than 20 years. With their expertise and experience, the expert panel had the ability to verify and validate the entities, and the relationships between entities within conceptual models.

Regarding the conceptual model of natural rubber production and distribution, all expert panel members indicated that the conceptual model covered the essential entities in the upstream natural rubber supply network. The relationships between entities are well presented, particularly in the relationship between replanting in the life cycle of rubber plantations and the production of latex. The main criticism voiced by the expert panel was that the conceptual model of natural rubber production and distribution did not capture the impact of external factors including latex price, fertilizer price, seed availability, and fertilizer within latex production, and the transformation of plantation areas.

For the conceptual model relating to key players' operations, all expert panel members indicated that the conceptual model reliably presents the activities and decision-making processes of key players. External factors that affect key players' decisions are also accurately presented. The expert panel indicated that there are small amounts of latex in some villages that are distributed directly to primary processors without passing through village suppliers and district suppliers. This is owing to the availability of rubber smallholders' cooperatives that have exist in agreements with primary processors around to latex supply. The main criticism of the expert panel around this conceptual model lay within the relationship of external factors to key players' decisions. For example, it was not clear how latex price affected the decision of rubber smallholders to replant their plantations. The criticisms from the expert panel around the proposed conceptual models have been used to inform data collection in the quantitative phase.

4.2 Decision Models of Key Players in the Upstream Natural Rubber Supply Network of North Sumatera

The upstream natural rubber supply network in Indonesia is dominated by individual actors, including rubber smallholders, village suppliers, and district suppliers. Interviews with natural rubber stakeholders in North Sumatera indicated that reductions in natural rubber supply are caused by the low productivity of rubber smallholders and rubber smallholders changing crops, while the growth of new rubber smallholders is low owing to unavailable land. Low productivity was attributed to smallholders' decisions to maintain their plantation by applying fertilizer. Moreover, the phenomenon of crop-switching is closely related to decisions of smallholders around replanting. These decisions are nonetheless influenced by many wider factors in the field, including latex price, the availability of government aid, and rubber seed price.

The verification and validation of conceptual models illustrates the need to ascertain links between external factors such as latex price, rubber seed price, availability of seed, and fertilizer price, in understanding latex production and distribution. It was found that these external factors have affected the decisions of key players in North Sumatera's natural rubber supply network. However, it was not clear how these external factors influence key players' decisions. Subsequently, a quantitative phase was designed to investigate how external factors influence the decisions of key players, as well as to configure the decision models of key players.

This section examines the important decisions of key players and the main factors influencing these decisions. Not all decisions from key players are modelled in this section. Only decisions that have a significant impact on natural rubber supply and on sustainability in the natural rubber supply network are selected for investigation and modelling. Table 4.5 shows the decisions from players that are selected.

These decisions were identified in the qualitative phase through the interview process with key players and relevant stakeholders (refer to section 4.1.2). These decisions were modelled using discrete choice experimentation through conducting surveys with key players in North Sumatera's natural rubber supply network. The survey used discrete choice questionnaires, which were developed based on external factors identified in the qualitative phase. The development of discrete choice questionnaires, the validation of questionnaires, and the completion of questionnaires is outlined in appendix B.

Table 4.5 Selected Decisions that are investigated in quantitative phase

Key Players	Decisions	Reason to be selected
Rubber Smallholders	Decision to apply fertilizer	It is recommended that fertilizer is applied to the plantation to maintain productivity. Many rubber smallholders do not apply fertilizer. Implementation of fertilizer is one activity that produces greenhouse gas emission.
	Decision to replant	Replanting is one key activity to sustain the rubber supply. However, it was found that in North Sumatera, many rubber smallholders decided not to replant their land. As a result, many old plantations (low-productive) exist in supply network.
Village Suppliers	Decision to determine latex price	Latex price at this level influences rubber smallholder income.
District Suppliers	Decision to determine latex price	Latex price at this level influences latex price at village supplier level. This price influences village supplier income

4.2.1 Decision Models of Rubber Smallholders

The purpose of this section is to present decision models for rubber smallholders, which were configured on the basis of data analysis from discrete choice experiments. There are two decision models for rubber smallholders, including decision models for giving fertilizer, and decision models for replanting. To illustrate the decision models, this section is divided into three sub-sections, including section 4.2.1.1 that introduces the profile of rubber smallholder respondents, section 4.2.1.2 that presents the decision model for applying fertilizer, and section 4.2.1.3 that presents decision models for replanting.

4.2.1.1 Profile of Rubber Smallholder Respondents

This section elaborates on the statistics of rubber smallholder respondents in the discrete choice experiment. Ninety rubber smallholders were interviewed from December 2015 to February 2016. Each respondent was required to fill out a socio-economic section before entering data into the discrete choice experiment section of the questionnaire. The socio-economic section of the questionnaire is designed to generate a profile of rubber smallholders. Table 4.6 gives descriptive statistics from 90 respondents.

Table 4.6 Descriptive Statistics from Socio-Economic Profile of Rubber Smallholder Respondents

Socio-Economic Profiles	**Categories**	**Frequency**	**Percentage**
Age	21-30 years old	6	6.7
	31-40 years old	23	25.6
	41-50 years old	24	26.7
	51-60 years old	20	22.2
	61-70 years old	17	18.9
	Total	90	
Education	completed junior school	27	30.0
	completed junior high school	13	14.4
	completed senior high school	42	46.7
	completed bachelor degree	8	8.9
	Total	90	
Plantation area	less than 1 Ha	26	28.9
	1-5 Ha	57	63.3
	5-10 Ha	4	4.4
	10-15 Ha	2	2.2
	More than 20 Ha	1	1.1
	Total	90	
Legality of land	Village Leader Certification	68	75.6
	District Leader Certification	17	18.9
	Full Certification by Indonesia Land Agency	5	5.6
	Total	90	
Total of dependent	1 person	13	14.4
	2 persons	16	17.8
	3 persons	21	23.3
	4 persons	25	27.8
	5 persons	10	11.1
	More than 5 persons	5	5.6
	Total	90	
Income per month	less than IDR 1,000,000	31	34.4
	between IDR 1,000,000 - IDR 2,000,000	32	35.6
	between IDR 2,000,000 - 3,000,000	19	21.1
	between IDR 3,000,000 - 4,000,000	2	2.2
	between IDR 4,000,000 - 5,000,000	1	1.1
	More than IDR 5,000,000	5	5.6
	Total	90	

Continues on the next page

Table 4.6 *Continued*

Socio-Economic Profiles	Categories	Frequency	Percentage
Side job	no	35	38.9
	yes	55	61.1
	Total	90	
Type of Side job	Agriculture	28	50.9
	employee	13	23.6
	livestock	1	1.8
	other	13	23.6
	Total	55	

As regards the age of respondents, the latter are dominated by rubber smallholders with an age range of 31-70 years. For the total number of respondents, 41% are aged 51 years and above. This indicates that rubber smallholders in this category are in a stage of shifting responsibility for plantation management to their descendants. In terms of education, only around 47% of respondents completed senior high school, and 9% of respondents completed a bachelor degree. This indicates that more than 40% of respondents have low education levels.

The majority of rubber smallholders own plantations with areas of less than 5 Hectares. Only 7% of rubber smallholders have plantations with areas of more than 5 Hectares. This fact is related to the income of smallholders gained from their plantations. Around 70% of respondents have incomes of less than IDR 2,000,000. Around 34% of respondents have incomes of less than IDR 1,000,000. This economic condition puts them at risk, as their incomes are less than the standard minimum income in the North Sumatera Province. Subsequently, the majority of respondents (around 61%) have sought out additional work (side jobs) owing to low incomes from plantations. Some of them work in the agricultural sector, while others work as employees in local government, and in private businesses near to their villages. They are, moreover, bound to supporting their dependents. Around 69% of respondents have 2-4 dependents.

In terms of the land legality of plantations, the majority of rubber smallholder respondents only have village leader certification or sub-district leader certification. However, this type of certification cannot be used to get a financial loan. As a result, this has put many rubber smallholders in a tough situation where need more support to develop their plantations but cannot access it.

4.2.1.2 Decision models for applying fertilizers to plantations

This section outlines the decision models of rubber smallholder for applying fertilizer. Rubber smallholders are recommended to use fertilizer in order to improve latex production from plantations. Fertilizer is used to provide enough nutrients in the land for the growth of rubber trees. As a result, the use of fertilizer at effective times and at the right doses is necessary for effective rubber plantations. However, rubber smallholders in Indonesia, mainly in the North Sumatera Province, have shown to reduce their use of fertilizer. Some smallholders do not use any fertilizer in their plantations owing to several reasons. As a result, the productivity of rubber plantations can diminish owing to a lack of nutrients for rubber trees.

Undertaking a qualitative study has shown the influential factors affecting rubber smallholders' decisions to use fertilizer. These influential factors have been arranged into different levels to define their effect on rubber smallholders' decisions (see appendix B1). Rubber smallholders' use of fertilizer is linked with significant factors in logistic regression analysis. Table 4.7 shows logistic regression results from surveys in the North Sumatera Province.

Table 4.7 Logistic Regression Results for Decisions to Use Fertilizer

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	fertilizerprice	-2.105	.266	62.537	1	.000	.122
	latexprice1	2.285	.164	193.119	1	.000	9.825
	fertilizeravailability	.277	.260	1.136	1	.286	1.320
	fertilizerimpact	.271	.263	1.066	1	.302	1.312
	Constant	-2.377	.791	9.035	1	.003	.093

It can be seen from Table 4.7 that fertilizer price and latex price are statistically significant factors affecting rubber smallholders' decisions to use fertilizer. An increase in fertilizer price influences rubber smallholders' decisions to use it. High fertilizer prices can push rubber smallholders to reduce the amount of fertilizer allocated for their plantation. This is shown by the negative relationship in the logistic regression results. Indonesia's government has a policy to subsidize fertilizer for smallholders, which helps smallholders to access cheap fertilizer to maintain the land. However, this policy is not well managed. As a result, some districts do not receive an appropriate allocation of subsidised fertilizer. This type of fertilizer is therefore only available at certain times. Rubber smallholders also have to purchase fertilizer at the unsubsidized normal price while rubber price is at a low level, although the implementation of fertilizer requires significant costs.

The price of latex is also found to have a significant effect on rubber smallholders' decisions. As it comprises a main source of income for rubber smallholders, the majority of rubber smallholders support their lives and the lives of their families on this income. Normally, income from plantations is divided into two allocations, for the maintenance of daily life and for the maintenance of the plantation. While latex prices remain low, the income from plantations is only enough to support the daily life of rubber smallholders. As a consequence, the allocation of income for plantations is neglected. This resonates with the logistic regression result showing positive links between latex prices and decisions to use fertilizer. This means that increases in latex price are likely to enhance the probability of rubber smallholders using fertilizer on their plantations.

Two other factors in the experiment have been found to be statistically insignificant in influencing the decisions of rubber smallholders to use fertilizer. The availability of fertilizer in one area cannot directly influence the decisions of smallholders in that area to use fertilizer. This owing to the fact that fertilizer located in the district capital or other villages will yet increase fertilizer cost by adding transportation costs. However, it was found that increased availability of fertilizer is likely to enhance the probability of fertilize user. Furthermore, although the impact of available fertilizer is not statistically significant, this variable has a positive link in the logistic regression results. This means that increased fertilizer impact is likely to enhance the probability of fertilizer use. Based on logistic regression analysis, the probability of rubber smallholders using fertilizer in North Sumatera Province can be calculated using the following equation:

$$P_{give\ fertilizer} = \frac{e^{-2.337+(-2.105)\ X_1+2.285X_2+0.277\ X_3+0.271\ X_4}}{1+e^{-2.337+(-2.105)\ X_1+2.285X_2+0.277\ X_3+0.271\ X_4}} \qquad \mathbf{4.1}$$

Where:

X_1 is fertilizer price, X_2 is latex Price, X_3 is availability of fertilizer, and X_4 is impact of fertilizer.

4.2.1.3 Decision model for replanting

This section outlines the decision model of rubber smallholders for replanting. Replanting is indicated as a key activity to sustain rubber supply. In Indonesia's natural rubber supply network, the decision of rubber smallholders to not replant their land is a main driver in the significant reduction of rubber supply. In a quantitative study, a discrete choice experiment was implemented to observe factors that influence the decisions of rubber smallholders to replant their land. Logistic regression results identified four factors as statistically significant in influencing the decisions of rubber smallholders, including palm oil price, seed price, the availability of seed, and government aid. Table 4.8 shows logistic regression analysis results for rubber smallholders' replanting decisions.

Table 4.8 Logistic Regression Result for Decisions around Replanting the Land

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	LatexPrice2	.099	.061	2.639	1	.104	1.105	.980	1.245
	PalmoilPrice	-.122	.062	3.910	1	.048	.885	.784	.999
	Priceofrubberwood	.111	.063	3.163	1	.075	1.118	.989	1.264
	seedprice	-.263	.138	3.622	1	.057	.768	.586	1.008
	availabilityofseed	-.284	.138	4.235	1	.040	.753	.574	.987
	availabilityofgovernmentaid	.484	.063	58.307	1	.000	1.623	1.434	1.838
	rubberreplantingcost	-.206	.139	2.196	1	.138	.814	.619	1.069
	Rubberreplantingtraining	.020	.138	.020	1	.887	1.020	.778	1.336
	Constant	-.986	.556	3.143	1	.076	.373		

The first significant factor shown is palm oil price. Palm oil is an alternative and popular crop in the North Sumatera Province. Palm oil and rubber are two dominant crops in North Sumatera Province. Many rubber smallholders subsequently consider the palm oil crop as an alternative while the rubber crop is no longer profitable. As a result, palm oil prices are used as a basis of comparison with the profitability of rubber plantations. The logistic results confirm this by showing a negative connection with rubber replanting decisions. An increase in palm oil price is likely to reduce the probability of rubber smallholders replanting their land.

Seed prices were also found to be statistically significant in influencing replanting decisions. Seeds are one factor affecting the productivity of plantations. High-quality rubber seeds will produce plantations with good productivity and able to withstand rubber plant fungus. However, in order to produce high quality rubber seeds, a carefully process around selecting seeds and sourcing seeds is required. For example, growing seeds until it can be planted is an important process that needs to be monitored intensively. As a result, to produce high quality seeds, production costs can be high, which in turn increases the price of rubber seed. The logistic regression results nevertheless show that increasing seed prices have a negative effect on replanting decisions, which reduces the probability of rubber smallholders to replant their land.

Owing to difficulties and the intensive process of producing good quality of seed, not all rubber smallholders have the ability to produce high quality seeds. In Indonesia's natural rubber supply network, only certified producers are able to sell rubber seeds. These seed producers are carefully monitored by the government to maintain high quality seeds. There are only a few numbers of certified rubber seed producers in the North Sumatera province. Total production for good quality rubber seed is consequently limited. As such, rubber seeds are not available in every district in the North Sumatera Province at all times. However, logistic regression shows that the availability of seeds can influence replanting decisions. The unavailability of rubber seeds at all times in a district can decline the probability of rubber smallholders to replant their land.

The low price of latex has influenced rubber smallholders' incomes. The daily expenditure of rubber smallholders sometimes cannot be covered by income from rubber plantations, if latex price is low. No further income can then be allocated for maintaining plantations and replanting. In such conditions, government aid is important for supporting replanting. Logistic regression results show that the availability of government aid can improve the probability of rubber smallholders replanting their land. It was also found that full government aid consisting of seeds, fertilizer, and replanting aid has the biggest effect on increasing the probability of replanting.

Logistic regression additionally shows that other factors in the experiment, including latex price, rubber wood price, replanting cost, and replanting training are not statistically significant. Latex prices are described as not statistically significant owing to the fact that when latex prices are low, rubber smallholders are likely to think about changing crops, and while latex prices are at a high level, rubber smallholders think hold old rubber trees to gain more profit. Furthermore, replanting costs were found to have a negative correlation with replanting decisions. This means that increased replanting costs are likely to reduce the probability of rubber smallholders replanting.

Rubber wood can be sold to wood processors within the network. However, rubber wood cannot be sold in all districts owing to the absence of wood processors. Moreover, many plantations only have a small amount of rubber wood when entering low-productive phases. This is because many rubber trees fall down during the productive phase because of fungus or wind, before entering the low-productive phase. As a result, many rubber smallholders do not consider rubber wood to be an alternative source of additional income to cover replanting costs. Logistic regression analyses nonetheless indicate that this factor has a positive correlation with the increased probability of rubber smallholders to replant.

The last factor comprises replanting training. This is not considered to be a statistically significant factor, owing to small numbers of rubber smallholders receiving replanting training. Not many stakeholders provide replanting training; only provincial government agencies provide this training, with a limited number of spaces available for rubber smallholders to join this program. As a result, many rubber smallholders are unable to get information and technology about the replanting process and plant protection. It was found that replanting training could increase the probability of rubber smallholders replanting. Based on the logistic regression analysis, the probability of rubber smallholders replanting in the North Sumatera Province can be calculated using the following equation:

$$P_R = \frac{e^{-0.986+0.099\,X_1-0.122\,X_2+0.111\,X_3-0.263\,X_4-0.284\,X_5+0.484\,X_6-0.206\,X_7+0.02\,X_8}}{1+\ e^{-0.986+0.099\,X_1-0.122\,X_2+0.111\,X_3-0.263\,X_4-0.284\,X_5+0.484\,X_6-0.206\,X_7+0.02\,X_8}} \qquad \textbf{4.2}$$

Where:

P_R = probability of rubber smallholder to replant their land, X_1 = latex price, X_2 = palm oil price, X_3 = rubber wood price, X_4 = seed Price, X_5 = availability of seed, X_6 = government aids, X_7 = replanting Cost, X_8 = replanting training.

A utility model can be applied to determine the probability of rubber smallholders using fertilizer and replanting their land, by considering different influential factors. Table 4.9 and 4.10 show the application of the utility models to predict the probability of fertilizer use and to replanting. It can be seen from Table 4.9 that the probability of using fertilizer will increase significantly when latex price is at its highest level (from experiment 2 and 4). Although the fertilizer price is high, the probability of using fertilizer is still high if latex price is at the highest level. The lowest probability of using fertilizer is found when fertilizer price is at the highest level and latex price is at the lowest level (experiment 3). The current conditions in North Sumatera are reflected in experiment 1 shown in Table 4.9. It can be seen that, despite fertilizer price being subsidised (IDR 120.000), the probability of using fertilizer is quite low while latex price is at the lowest level (IDR 5.000). This indicates that the probability of rubber smallholders using fertilizer in the North Sumatera Province is currently very low.

Table 4.10 shows that likelihood of replanting is increases where complete government aid is available. Even where latex price is at its lowest level (in experiment 4), the availability of government aid can enhance the probability of rubber smallholders replanting. It was found that the palm oil price also has a big impact on replanting decisions. This can be seen in experiment 5; although latex price is at its highest level (IDR 12.500), the probability of rubber smallholders replanting is quite low while palm oil price is at the second level (IDR 2.000). The current situation in North Sumatera Province is reflected by experiment 1 in Table 4.10. It can be observed from this that the probability of rubber smallholders replanting is quite low while latex price is at its lowest level (IDR 5.000) and no government aid is available. This result confirms that the high number of low-productive areas in several districts of North Sumatera Province is caused by a majority of rubber smallholders with low-productive areas in those districts not replanting their plantations.

Table 4.9 Example of Calculation for Probability of Rubber Smallholder to Give Fertilizer

Experiment	Influential Factors				Probability of Rubber Smallholder to Use Fertilizer
	Fertilizer Price (IDR)	Latex Price (IDR)	Availability of Fertilizer	Fertilizer Impact	
1	120,000	5,000	available in certain time	10	0.161
2	120,000	12,500	available all the time	30	0.996
3	300,000	5,000	available all the time	30	0.038
4	300,000	12,500	available all the time	30	0.974
5	300,000	7,500	available all the time	10	0.232

Table 4.10 Example of Calculation for Probability of Rubber Smallholder to Replant

Experiment	Influential Factors								Probability of Rubber Smallholder Replanting
	Latex Price (IDR)	Palm oil price (IDR)	Rubber wood price (IDR)	Rubber Seed Price (IDR)	Availability of Rubber Seed	Types of Government aid	Replanting Cost (IDR)	Replanting Training	
1	5,000	1,000	0	7,000	Do not meet demand	No aid	7,500,000	Never	0.241
2	12,500	1,000	7,500,000	7,000	Meet Demand	seeds, fertilizers and replanting cost aid	15,000,000	Ever	0.614
3	10,000	4,000	0	13,000	Do not meet demand	seeds, fertilizers and replanting cost aid	7,500,000	Never	0.468
4	5,000	2,000	5,000,000	13,000	Meet Demand	seeds, fertilizers and replanting cost aid	15,000,000	Ever	0.418
5	12,500	2,000	2,500,000	13,000	Do not meet demand	No aid	7,500,000	Never	0.245

4.2.2 Decision Model of Village Supplier

The purpose of this section is to present a decision model for village suppliers. This model is configured to reflect the ways that village suppliers determine latex prices for rubber smallholders. This section is divided into two sub-sections: sub section 4.2.2.1 delivers a profile of village supplier respondents, and sub section 4.2.2.2 presents the decision model for determining latex prices at village level.

4.2.2.1 Profile of Village Supplier Respondents

This section presents a profile of village supplier respondents involved in the discrete choice experiments. 31 village suppliers were interviewed in the course of this experiment. A low number of village supplier respondents in this survey was caused by the lack of a village suppliers' database, which created difficulties in finding respondents. Furthermore, many village suppliers did not want to be interviewed and their locations were not accessible by car. Reasons behind village suppliers not wanting to be interviewed were that they were concerned about being asked about latex price. Although the researcher provided a guarantee of data confidentiality, many of them still did not want to be surveyed. Each respondent was required to fill in a socio-economic section. This section consisted of questions related to socio-economic variables such as age, education level, income, and total number of dependents. This information is presented in a descriptive analysis that can be observed in Table 4.11.

Table 4.11 Descriptive Statistic of Village Supplier Respondents

Socio-economic Profiles	Categories	Frequency	Percentage
Age	21-30 years old	2	6.5
	31-40 years old	10	32.3
	41-50 years old	9	29.0
	51-60 years old	5	16.1
	61-70 years old	5	16.1
	Total	31	
Education	completed junior school	5	16.1
	completed junior high school	7	22.6
	completed senior high school	17	54.8
	completed bachelor degree	2	6.5
	Total	31	
Range of area buying latex	1-5 Km	18	58.1
	5-10 Km	7	22.6
	10-15 Km	3	9.7
	15-20 Km	3	9.7
	Total	31	

Continues on next page

Table 4.11 Continued

Socio-economic Profiles	Categories	Frequency	Percentage
Legality of vehicle	Vehicle is rent	12	38.7
	Vehicle is owned	19	61.3
	Total	31	
Amount of latex supplied per week	0-250 Kg/week	5	16.1
	250-500 Kg/week	10	32.3
	500-750 Kg/week	5	16.1
	750-1,000 Kg/week	5	16.1
	More than 1,000 Kg/week	6	19.4
	Total	31	
Total number of dependents	1 person	6	19.4
	2 persons	5	16.1
	3 persons	8	25.8
	4 persons	8	25.8
	5 persons	1	3.2
	More than 5 persons	3	9.7
	Total	31	
Income per month	less than IDR 1,000,000	5	16.1
	between IDR 1,000,000 - IDR 2,000,000	11	35.5
	between IDR 2,000,000 - 3,000,000	6	19.4
	between IDR 3,000,000 - 4,000,000	6	19.4
	between IDR 4,000,000 - 5,000,000	1	3.2
	More than IDR 5,000,000	2	6.5
	Total	31	
Side job	no	6	19.4
	yes	25	80.6
	Total	31	
Type of side job	Agriculture	19	76.0
	livestock	2	8.0
	other	4	16.0
	Total	25	

From Table 4.11, it can be seen that village supplier respondents are dominated by people between 31 to 50 years old. Only 32% of village suppliers exceeded the age of 50. This indicates that the profession requires intensive communication to construct networks and relationships with rubber smallholders. This is important because rubber smallholders are a source of latex. A good relationship is also required with district suppliers as the channel for supplying latex to the next stage in the network. As a result, it was found that not many people at an age of 30 years and under are working as village suppliers. It is very difficult to compete with current competitors that already have a good relationship with rubber smallholders and district suppliers. In term of education, around 55% of respondents completed senior high school. However, almost 39% of respondents have a low level of education.

In term of operations, around 58% of respondents collect latex from rubber smallholders that are located within 5 km of their own position. Only 22% of respondents collect latex from plantations, which are located between 5-10 km from their own area. The dimensions of the area for buying latex depend on the total area of the village. Some villages have a large area with a diameter of more than 5 km. Around 61% of respondents use their own vehicle to pick up latex from plantations, while another 38% of respondents rent a vehicle to pick up latex. As regards the amount of latex that is accumulated every week, around 48% of respondents accumulate latex at less than 500 kg per week. 32% of respondents accumulate latex of around 500-1,000 kg per week. Only 19% of respondents could accumulate latex of more than 1,000 kg per week.

The total amount of latex influences the income of the village supplier. According to Table 4.11, only 16 % of respondents have an income of less than IDR 1,000,000 per month from their activities as a village supplier. Around 84% of respondents have an income of more than IDR 1,000,000. This condition shows that the profession can reach a minimum standard of income in the North Sumatera Province. The income is used to support village suppliers' daily lives and those of their dependents. It was found that around 87% of respondents have 1-4 dependents. Although the income is higher than the standard minimum income, owing to the increased cost of living, income from village supplier professions is no longer enough to support their livelihoods. As a result, 80% of respondents need another job. 76% of side jobs done by village suppliers are still in the agricultural field. This indicates that village supplier duties are not often the main professions for these people.

4.2.2.2 Decision Model for Determining Latex Prices at Village Level

This section introduces the decision model for village suppliers determining the price of latex at the village level. This price is fundamental in the maintenance of economic and social sustainability in the upstream natural rubber supply network. Rubber smallholders' income and village suppliers' income are influenced by latex prices. In the North Sumatera natural rubber supply network, latex prices at village level are influenced by several factors. A discrete choice experiment was conducted to investigate the factors influencing village suppliers' decisions in determining latex prices at village level. A regression model of latex prices at the village level was additionally achieved by analysing the discrete choice experiment results. Table 4.12 shows the logistic regression results for determining latex prices at the village level.

Logistic regression results show that there are four statistically significant factors influencing latex prices at village level, including the dry rubber price at the primary processor, the distance of village suppliers to rubber smallholders' plantations, dry rubber content, and profit options. Dry rubber prices at the primary processor comprise the prices for dry latex at the primary processor. This price changes daily according to international rubber prices e.g. SICOM (Singapore's Commodity). This price is the basis for the village supplier to determine latex prices at the village level. Logistic regression shows that the dry rubber price at the primary processor has a positive effect on the latex price at the village level.

Table 4.12 Logistic Regression Results for Decisions around Determining Latex Price at the Village Level

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Dryrubberpriceatprimaryprocessor	.195	.088	4.979	1	.026	1.216
	Tranportationcost	-.028	.088	.099	1	.753	.973
	Weightoflatexbeingoffered	.106	.088	1.449	1	.229	1.112
	Distance	-.191	.089	4.555	1	.033	.826
	Dryrubbercontent	.279	.088	9.970	1	.002	1.321
	Totalofrival	.003	.199	.000	1	.987	1.003
	Optionofprofit	.350	.089	15.519	1	.000	1.420
	Constant	-2.039	.662	9.471	1	.002	.130

Distance from plantation influences latex prices owing to the effort implemented by village suppliers in picking up latex. Long distances require greater efforts from village suppliers in picking up latex. The results from logistic regression confirm this by showing the impact that such negative effects have on the probability of latex prices being implemented by village suppliers. Dry rubber content is used to measure the standard quality of rubber. At the village level, the dry rubber content of coagulant latex is predicted by village suppliers owing to the unavailability of tools to examine the dry rubber content accurately. This prediction is used in the calculation of latex price at the village level. Logistic regression shows a positive correlation between dry rubber content and the probability of latex prices being implemented by village supplier. Options around profit are found to be a statistically significant factor influencing the price of latex at village level. Village suppliers consider profit gained from one transaction as a determinant of latex prices. Logistic regression shows that increase in profit will increase the probability of latex prices being implemented by village suppliers.

Three other factors in this experiment are not considered as statistically significant, including transportation cost, the weight of latex, and total number of competitors. Since transportation costs were found to be small, village suppliers do not consider them negatively effect their profitability. Logistic regression results show that this factor does not significantly influence village suppliers in determining price. From descriptive statistics, around 64% respondents supplied between 0-750 kg of latex per week. Rubber smallholders usually provide latex at a similar weight because latex is produced from plantation areas of less than five Ha. As a result, there is not too much difference between smallholders in term of weight. Logistic regression shows that the weight of latex does not significantly influence village suppliers in determining the price of latex at village level. The number of village suppliers operating in one village reflects the competition between those suppliers in gaining latex from rubber smallholders. However, the total number of competitors is not a statistically significant factor influencing the construction of latex price. This is owing to the fact that each village supplier has ties with several rubber smallholders. These rubber smallholders are thus likely to sell their latex to certain village suppliers. Based on logistic regression results, the probability of village suppliers to implement a latex price at village level can be calculated using the following equation:

$$P_A = \frac{e^{-2.039+\,0.195\,X_1-0.28\,X_2+0.106\,X_3-0.191\,X_4+0.279\,X_5+0.03\,X_6+\,0.35\,X_7}}{1+\,e^{-2.039+\,0.195\,X_1-0.28\,X_2+0.106\,X_3-0.191\,X_4+0.279\,X_5+0.03\,X_6+\,0.35\,X_7}} \qquad \textbf{4.3}$$

Where:

X_1 = dry rubber price, X_2 = transportation cost, X_3 = weight of latex, X_4 = distance to plantation, X_5 = dry rubber content, X_6 = number of competitors, X_7 = option of profit

The equation above is used to calculate the probability of latex price being implemented by the village supplier. Village suppliers calculate latex price using the equation:

(DRP * DRC * (1 - % of shrinkage) – (DSC + DSP) – (VSC + VSP)

Where

DRP = dry rubber price at primary processor; DRC = dry rubber content (this detected visually by village supplier); % shrinkage = % of water reduction from wet latex (usually 10-30% depend on district area; DSC = district supplier cost (usually around IDR 400-600 per kg, including transportation cost and labour cost); DSP = profit for district supplier (usually around IDR 0-1000 per kg depend on district); VSC = village supplier cost (usually for transportation, it is around IDR 10-50 per K kg); VSP = village supplier profit (it is around IDR 0-600).

Equation 4.3 can be used to calculate the probability of certain latex prices applied by village suppliers. Table 4.13 gives an example of latex price calculation and the probability of village suppliers' implementation of it in their practices.

Table 4.13 Example of Latex Price Calculation and Probability of Village Suppliers' Implementation of the Price

Experiment	Dry Rubber Price at Primary Processor (IDR/Kg)	Transportation Cost (IDR)	Weight of wet latex (Kg)	Distance (Km)	Dry Rubber Content (%)	Total of rivals (People)	Option for Profit (IDR)	Latex Price at Village level (IDR)	Probability of village supplier implementing this price
1	13,000	18,000	0-150 Kg	6-10 Km	56-60%	5-10	Rp151- Rp 300	6,000	0.4932
2	13,000	21,900	151-300 Kg	11-15 Km	40-45%	0-5	Rp 451 – Rp 600	4,000	0.30379
3	13,000	18,000	301-450 Kg	6-10 Km	51-55%	0-5	Rp 451 – Rp 600	5,100	0.3204
4	13,000	20,700	151-300 Kg	16-20 Km	56-60%	5-10	Rp 301- Rp. 450	5,900	0.58709
5	13,000	21,900	451-600 Kg	11-15 Km	46-50%	5-10	Rp151- Rp 300	4,900	0.3426

(%Shrinkage = 10%, DSC = IDR 500/Kg, DSP = IDR 200/Kg)

Example calculation for experiment one (in IDR)

Latex Price at Village Level = (13,000 * 0.6 * (1-0.1)) – (500 +200) – (36+300) = 5,984 (6,000)

4.2.3 Decision Model of District Supplier

The purpose of this section is to present the decision model for district suppliers. This decision model reflects the way the district supplier determines latex price at the district level. This section is divided into two sub-sections: sub-section 4.2.3.1 presents a profile of district supplier respondents, and sub section 4.2.3.2 presents a decision model for determining price at the district level.

4.2.3.1 Profile of District Supplier Respondents

This section presents a profile of district supplier respondents gathered through a discrete choice experiment. 36 district suppliers were interviewed from December 2015 to February 2016. Owing to the lack of a database of district suppliers, snowball sampling was conducted. Based on information from village suppliers, rubber smallholders, and village officer, locations of district suppliers were identified. From this list, many district suppliers were unable to be interviewed, as they were not in their stated locations when the researcher visited them, or did not want to be interviewed. As a result, only 36 respondents were interviewed. During the interview, socio-economic profiles of the district supplier including age, education level, and their area range for purchasing latex were ascertained in the first section of questionnaire. This information has been summarised in Table 4.14.

Table 4.14 Descriptive Statistics of District Supplier Respondents

Socio Economic Profiles	Categories	Frequency	Percent
Age	21-30 years old	3	8.3
	31-40 years old	14	38.9
	41-50 years old	15	41.7
	51-60 years old	3	8.3
	61-70 years old	1	2.8
	Total	36	100.0
Education	completed junior school	2	5.6
	completed junior high school	6	16.7
	completed senior high school	22	61.1
	completed bachelor degree	6	16.7
	Total	36	100.0
Range of latex-purchasing area	0-50 Km	17	47.2
	50-100 Km	9	25.0
	100-150 Km	2	5.6
	150-200 Km	1	2.8
	More than 200 Km	7	19.4
	Total	36	100.0

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Table 4.14 *Continued*

Socio Economic Profiles	Categories	Frequency	Percent
Legality of vehicle	Vehicle is rented	18	50.0
	Vehicle is owned	18	50.0
	Total	36	100.0
Amount of latex supplied per week	0-10 tonnes/week	18	50.0
	10-20 tonnes/week	9	25.0
	20-30 tonnes/week	6	16.7
	30-40 tonnes/week	1	2.8
	More than 40 tonnes/week	2	5.6
	Total	36	100.0
Total number of dependents	2 persons	8	22.2
	3 persons	15	41.7
	4 persons	7	19.4
	5 persons	5	13.9
	More than 5 persons	1	2.8
	Total	36	100.0
Income per month	less than IDR 2,500,000	11	30.6
	between IDR 2,500,000 - IDR 5,000,000	8	22.2
	between IDR 5,000,000 - 7,500,000	7	19.4
	between IDR 7,500,000 - 10,000,000	8	22.2
	More than IDR 12,500,000	2	5.6
	Total	36	100.0
Side job	no	12	33.3
	yes	24	66.7
	Total	36	100.0
Type of side job	Agriculture	18	75.0
	employee	1	4.2
	other	5	20.8
	Total	24	100.0

From Table 4.14, it can be seen that respondents are dominated by district suppliers between 31-50 years old (around 80% of respondents). Only 8% of respondents were aged under 30 years old. Being a district supplier is a profession that requires good communication skills to develop networks with village suppliers from different villages. It is therefore difficult for new actors to enter the supply network system. New players have to compete with current agents who already have a network and good communications with village suppliers. Respondents who were less than 30 years old comprise respondents that are continuing their parents' businesses as district suppliers. In term of educational levels, the majority of respondents – around 78% – had completed senior high school level. Around 16% of respondents had completed a bachelor degree program.

In term of operations, around 80% of respondents seek out latex within an area of 0-200 km. This indicates that the majority of respondents focus on getting latex from villages inside their district. Only 19% of respondents seek out latex at distances of more than 200 km, or in neighbour districts. The latter occurs if the supply from their districts reduces significantly. In term of vehicles, 50% of respondents rent a vehicle for supplying latex. Another 50% of the respondents own vehicle for supplying latex. In term of latex amounts, 75% of respondents accumulate less than 20 tonnes of latex per week. This amount depends on the total amount of latex available in that district, and the number of district suppliers operating in that district.

In term of income, district suppliers produce better incomes, with around 70% of respondents generating an income of more than IDR 2,500,000 per month. Only 30% of respondents confessed to making an income of less than IDR 2,500,000 per month. These comprise good conditions for supporting their lives and those of their dependents. Around 82% of respondents have to support 2-4 people in their families. Furthermore, around 66% of respondents have a side job to support their lives and 75% of side jobs remain in the agricultural area.

4.2.3.2 Decision Model for Determining Latex Price at District Level

This section introduces the decision model of district suppliers for determining latex prices at district level. This price influences the economic and social sustainability of players in the North Sumatera natural rubber supply network, including the income of village suppliers and district suppliers. The decisions of district suppliers to determine latex price is influenced by several factors. A discrete choice experiment was conducted to identify significant factors that influence district supplier decisions. This experiment produced a utility model to predict the probability of latex prices being implemented at district level. Table 4.15 shows the logistic regression analysis for implementing latex prices at the district level.

According to the logistic regression results, six factors are found to be statistically significant in influencing the construction of latex prices at the district level. These are: the dry rubber price at the primary processor; dry rubber content; the weight of latex; distance; the total number of competitors; and options regarding profit. The dry rubber price at the primary processor comprises a basis for district suppliers to calculate latex price. The results of logistic regression confirm this by categorizing this factor as statistically significant.

Dry rubber content is used as a standard to measure the quality of latex in the primary processor. The primary processor calculates the latex price based on its dry rubber content. As a result, the district supplier uses dry rubber content to measure the quality of latex from village suppliers, although this can only be visually predicted. According to the results of logistic regression, dry rubber content is statistically significant in influencing the construction of latex price at a district level.

Table 4.15 Logistic Regression Result for Decisions around Latex Price at a District Level

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	Dryrubberpriceatprimaryprocessor	.129	.096	1.796	1	.180	1.138
	Tranportationcost	-.059	.103	.326	1	.568	.943
	Dryrubbercontent	.131	.095	1.891	1	.169	1.140
	Weightoflatexbeingoffered	.665	.102	42.402	1	.000	1.944
	Distance	.092	.096	.929	1	.335	1.097
	Totalofrival	-.382	.213	3.220	1	.073	.682
	Availabilityoflatex	-.035	.097	.128	1	.720	.966
	Optionofprofit	.444	.098	20.424	1	.000	1.558
	Constant	-3.333	.836	15.887	1	.000	.036

The weight of latex is critical for district suppliers. Total amounts of latex collected from village suppliers must reach the capacity of district suppliers' vehicles. If the total weight of latex is less than the capacity of vehicle, this will increase transportation costs per kg of wet latex. As a result, the logistic regression analysis shows that this factor significantly influences the decision of district suppliers in determining prices.

Distance is a critical factor for district supplier. An increase in distances could increase the risk for district suppliers. Hence, the majority of district suppliers will choose the nearest primary processor as a supply destination. This situation is reflected in the logistic regression results that categorize this as a statistically significant factor. The number of competitors is also a significant factor influencing latex price. Conditions of competition for district suppliers are not comparable with those of village suppliers. Many district suppliers operating in the same area or district can reduce the amount of latex that can acquired, or can reduce the probability of accessing latex. Competition influences latex price at the district level where all district suppliers try to offer the best price to village suppliers. An increasing number of competitors will therefore significantly influence the price implemented by district suppliers. Options around profit also significantly influence latex price. If a district supplier wants to gain a higher profit, a higher latex price will be announced. On the contrary, if a district supplier wants a competitive price owing to the presence of competitors, profit levels will be reduced. Most district suppliers will nonetheless seek a high profit. As a result, profit options will significantly influence the creation of latex prices by district suppliers.

From the eight factors that have been investigated, only two factors are not considered to be statistically significant. These are transportation costs and the availability of latex from villages. Transportation cost is not significant because of the fact that this cost is added to the latex price. As such, district suppliers basically do not cover this cost because it has been included in the latex price. The availability of latex is not taken into account by district suppliers in determining price. District suppliers are able to acquire latex from several villages within their district. If latex supplies in one district are depleted, district suppliers will try to find latex from other districts.

Based on the logistic regression result, the probability of prices being implemented by district suppliers can be calculated using the equation:

$$P_A = \frac{e^{-3.333+0.129X_1-0.059X_2+0.131X_3+0.665X_4+0.092X_5-0.382X_6-0.035X_7+0.444X_8}}{1+e^{-3.333+0.129X_1-0.059X_2+0.131X_3+0.665X_4+0.092X_5-0.382X_6-0.035X_7+0.444X_8}} \qquad \textbf{4.4}$$

Where:

X_1 = dry rubber price at IDR 18.000, X_2 = transportation cost, X_3 = weight of latex, X_4 = distance to primary processor, X_5 = dry rubber content, X_6 = number of competitors, X_7 = availability of latex, X_8 = profit options

District suppliers calculate latex price using the equation below:

(DRP * DRC * (1 - % of shrinkage) – (DSC + DSP)

Where

DRP = dry rubber price at primary processor, DRC = dry rubber content (this detected visually by village supplier), % shrinkage = % of water reduction from wet latex (usually 10-30% depend on district area, DSC = district supplier cost (usually around IDR 150-600 per kg, including transportation cost and labour cost), DSP = profit for district supplier (usually around IDR 0-1000 per kg depending on the district). Equation 4.4 can be applied to calculate the probability of latex prices implemented by district suppliers. Table 4.16 shows the calculation of latex price at the district level, and the probability of district suppliers implementing it.

Table 4.16 Example of Latex Price Calculation and Probability of District Suppliers Implementing this Price

Set	Dry Rubber Price at Primary Processor (IDR/Kg)	Transportation cost (IDR)	Dry Rubber Content (%)	Weight of Wet Latex (Ton)	Distance from Village to primary processor (Kg)	Total number of Competitors (People)	Availability of latex from village (Ton)	Profit Options (IDR/Kg)	Latex price at district level (IDR)	Probability
1	13,000	1,500,000	56-60%	More than Ton	201-300 Km	2	10-15 ton	0- 250	6,400	0.43653
2	13,000	2,500,000	51-55%	Less than 500 Kg	101-200 Km	0-5	More than 15 ton	251- 500	5,500	0.13391
3	13,000	2,000,000	40-45%	500 Kg – 1 ,5 Ton	201-300 Km	5-10	More than 15 ton	751 –1,000	3,965	0.48001
4	13,000	2,500,000	56-60%	1,5 Ton – 3 Ton	0-100Km	0-5	5-10 ton	751 –1,000	5,600	0.76417
5	13,000	1,500,000	51-55%	500 Kg – 1 ,5 Ton	More than 300 Km	5-10	0-5 ton	501- 750	5,435	0.66187

(% shrinkage = 10 %)

4.3 Summary

This chapter has presented essential issues and a depth of understanding around Indonesia's upstream natural rubber supply network, including natural rubber production and its distribution system, as well as identifying important decisions made by players in the upstream North Sumatera Province natural rubber network. Two conceptual models were constructed to describe North Sumatera's natural rubber supply network. The first conceptual model shows how replanting can affect the composition of rubber plantation areas, latex production, and distribution. Based on this conceptual model, the formulation of replanting policies should consider the composition of rubber plantation areas within the supply network. Failed to consider this, might increase a risk for reduction of supply in future due to many rubber plantations areas enter low productive phase at the same time as it is happening in North Sumatera natural rubber industry.

The second conceptual model shows the operations and the decisions of key players in North Sumatera's upstream natural rubber supply network. It has been found that several external factors affect the decision of key players. For example, the unwillingness of rubber smallholders with low-productive areas to replant is influenced by several external factors. Based on this conceptual model, the formulation of replanting policies needs to consider how the key players make decisions and what factors influence those decisions.

Further investigation has been conducted to examine these external factors influence key players' decisions. For rubber smallholders, two decisions have been investigated, including choices around fertilizer use and decisions to replant. Fertilizer price and latex price have been found to be statistically significant factors influencing decisions to use fertilizer, while palm oil price, rubber seed price, the availability of rubber seed, and the availability of government aid have all been found to be statistically significant factors affecting decisions to replant. For suppliers, decisions around latex price construction were investigated. It was found that the dry rubber price at primary processors, the distance of village suppliers to rubber smallholders' plantations, the dry rubber content, and options around profit significantly affected the construction of latex price at the village level. At the district level, the construction of latex prices were significantly influenced by dry rubber prices at the primary processor level, dry rubber content, the weight of latex, distance, the total number of competitors, and options around profit. The relationship between influential factors and players' decisions has been used to construct utility models, which can be subsequently used to predict those decisions.

Chapter 5
An Approach for Formulating Sustainable Replanting Policies

This chapter introduces an approach for formulating sustainable replanting policies. The approach consists of a process, sustainability indicators, and a strategic planning tool. The chapter reports the second stage of the research process as illustrated in Figure 5.1, and is divided into five sections. Section 5.1 introduces the process formulating sustainable replanting policies. This is followed by outlining the sustainability indicators for use in the formulation of replanting policies, in Section 5.2. Section 5.3 presents the strategic planning tool for formulating sustainable replanting policies, and the verification and validation of the tool in Section 5.4. Finally, Section 5.5 presents a summary of Chapter 5.

5.1 Process for Formulating Sustainable Replanting Policies

The process for formulating sustainable replanting policies in the natural rubber supply network is based on a synthesis of information from literature and case studies. Exploring contemporary literature allows us to conclude that a high priority in the improvement of sustainability lies in the use of aspects from the three sustainability dimensions to inform decision-making process across the supply network. In parallel to this, conclusions from the case study indicate the importance of replanting as a central component in sustaining the supply of natural rubber from Indonesia’s natural rubber industry. Replanting is also found to affect the production and distribution of natural rubber, as well as the performance of key players. In order to develop replanting policies within the supply network, environmental, economic, and social impacts resulting from replanting must therefore be considered. Based on these insights, a process has been devised for using sustainability aspects to inform the formulation of replanting policies. This process is presented in Figure 5.2 using a flowchart diagram.

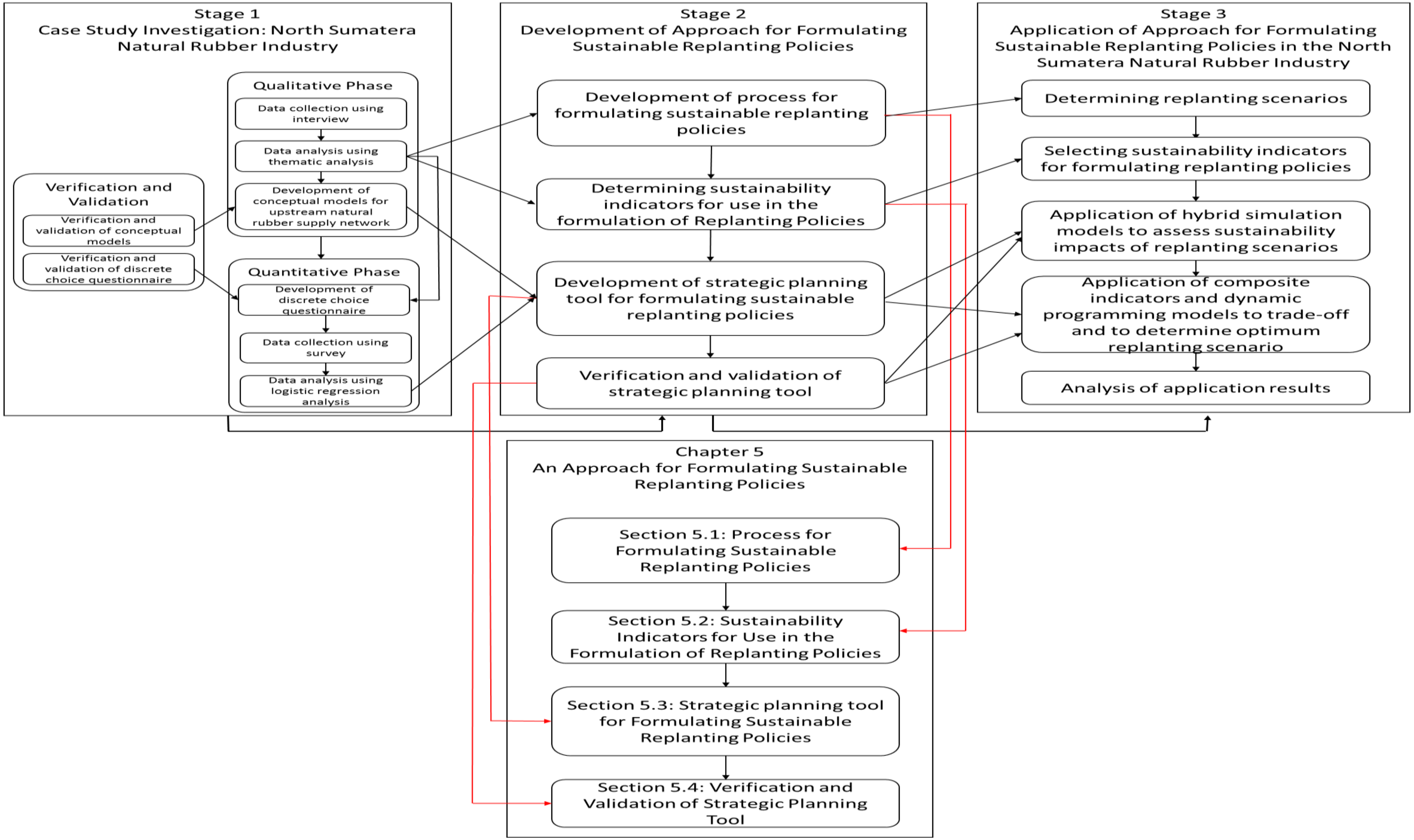

Figure 5.1 The Relationship between the Research Process and Chapter 5

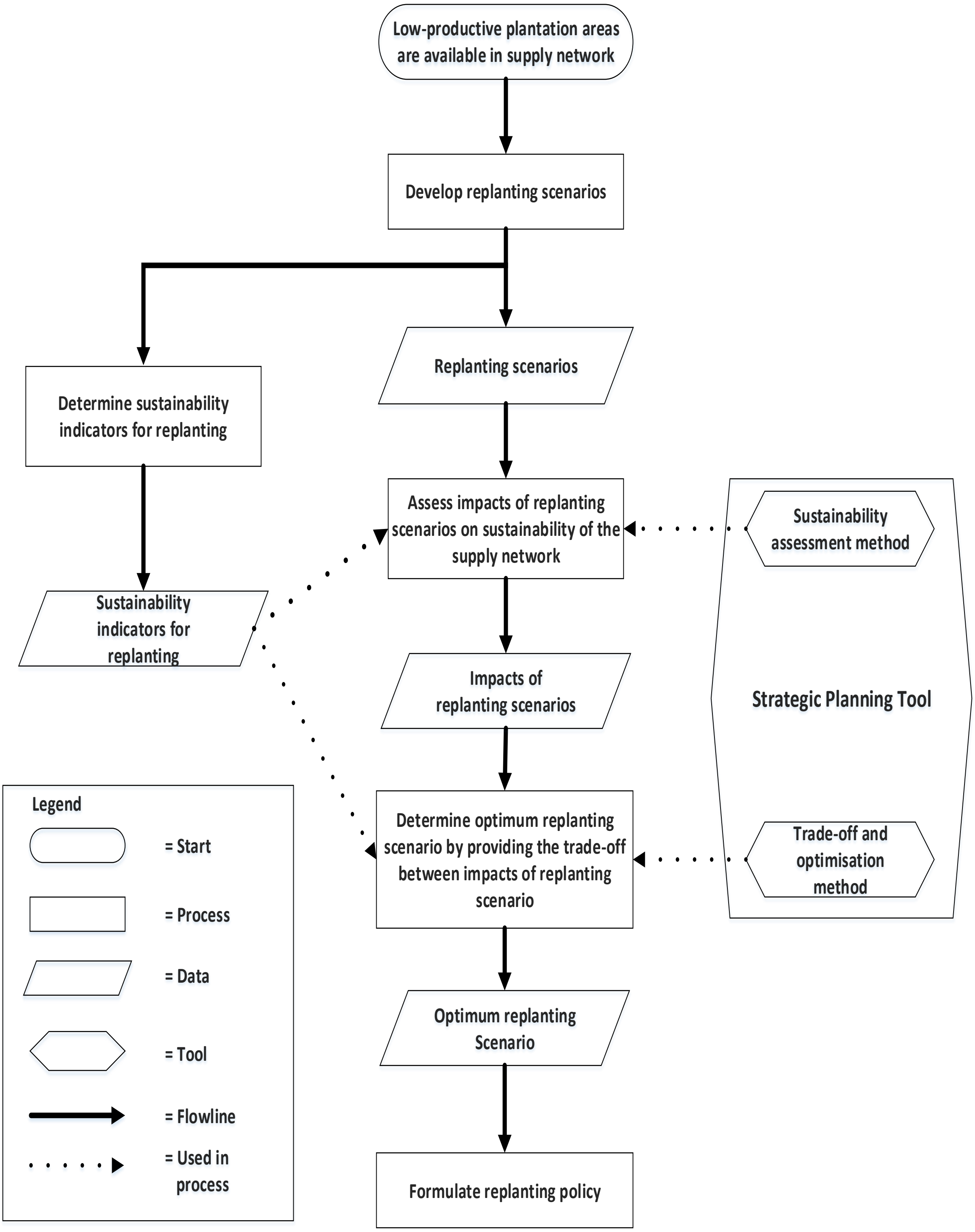

Figure 5.2 Process for Formulating Sustainable Replanting Policies

Figure 5.2 highlights the steps and methods used for the formulation of sustainable replanting policies. It begins from the point at which low-productive areas are identified in the supply network. The first step is to develop replanting scenarios. The latter refer to several allocations of low-productive areas within the network that are earmarked for replanting. Replanting scenarios are constructed by related policy-makers, such as provincial government agents and natural rubber primary processor associations, who devise scenarios according to existing constraints. These constraints may include the availability of resources and funding to support replanting. The next step is to assess the impact of replanting scenarios on the sustainability of the overall supply network. This step highlights the need for a sustainability assessment method and associated indicators. The sustainability indicators are then used to quantify the effects of replanting, while the sustainability assessment method is used to generate values of indicators in order to measure impacts.

The next step is to determine an optimum replanting scenario. In this process, a trade-off between the impacts of different replanting scenarios is ascertained. To do this, data related to the impacts of replanting scenarios is required, that subsequently feeds into trade-offs and optimisation methods. Sustainability indicators are also required in this process. In the final step, the replanting policy is formulated, guided by optimum replanting data. The formulation of policy consists of the allocation of funding and resources to implement optimum replanting in the supply network. Table 5.1 gives an example of the kind of data that flows through this process.

Table 5.1 Simple Examples of Data Use in the Process for Formulating Sustainable Replanting Policies

Process in Framework	**Example**
Low-productive plantation areas are available in supply network	In Langkat district, there were 243 Ha hectares of low-productive areas in 2015. These low-productive areas will change dynamically over the next five years (2016-2020).
Develop replanting scenarios	Replanting is planned for the next five years (2016-2020). Examples of allocations of low-productive areas planned for replanting for each year are 0, 100 Ha, 200 Ha, 300 Ha, 400 Ha and 500 Ha.

Continues on next page

Table 5.1 *Continued*

Determine replanting indicators	Several indicators including latex production, population of tappers, and carbon stock level are selected to assess the effects of replanting scenarios
Assess impacts of replanting scenario	If 100 Ha replanting is carried out in year 2016, total latex production in year 2022 will be around 20,000 Tonne, carbon stock level in year 2016 will be around 250,000 tonnes of C emission, and the population of tappers in year 2016 will be around 8500
Determine optimum replanting scenario	From the six allocations (0,100,200,300,400,500), allocation 100 Ha is found to have the best impact in the year 2016, while allocation 300 Ha is found to have the best impact in the year 2017.
Formulate replanting policies	If replanting a 1 Ha rubber plantation requires IDR 20M, the allocation of IDR 2,000 M (100 * IDR 20 M) is required in year 2016, and the allocation of IDR 6,000 M is required in year 2017 to support replanting in the Langkat district.

5.2 Sustainability Indicators for Use in the Formulation of Replanting Policies

This section introduces the sustainability indicators used in the formulation of replanting policies. Sustainability indicators are required to quantify the impact of replanting on the sustainability of the supply network. Sustainability indicators were constructed using information from the case study and literature review. From the case study investigation, replanting was found to have impacts on the sustainability of the supply network at the district level and at an individual level (i.e. in the performance of key players). As a result, indicators for both district level and individual level are provided. Indicators for district level represent economic, social, and environmental conditions in a targeted district or region, while indicators at the individual level represent the economic, social, and environmental state for key players in each targeted district. Table 5.2 summarises the indicators used for integrating sustainability goals into the development of replanting policies.

Table 5.2 Sustainability Indicators for the Formulation of Replanting Policies

Sustainability Dimensions	Replanting Indicators	Level	Unit
Economic dimension	Latex production	District level	kg
	Population of smallholders with immature land	District level	People
	Utilization of primary processor	District level	-
	Stock of latex for key players	Individual level	kg
	Key players' income	Individual level	IDR
Environmental dimension	Emissions from the application of fertilizer	District level	kg CO_2 e
	Emissions from the application of herbicide	District level	kg CO_2 e
	Emissions from replanting	District level	kg CH_4 e and kg N_2O e
	Carbon sequestration	District level	Ton CO_2
	Carbon stock	District level	Ton C
	Travel distance by supplier	Individual level	m
Social dimension	Population of smallholders	District level	People
	Population of tappers	District level	People
	Population of village suppliers	District level	People
	Population of district suppliers	District level	People
	Population of traders	District level	People

5.2.1 Indicators for economic dimensions

There are five main indicators for quantifying the effects of replanting on the economic circumstances of the supply network: total latex production, the population of smallholders with immature lands, the utilization of primary processors, the stock of latex among key players, and key players' income. The main economic indicator is total latex production. Since the aim of sustainable development is to ensure both current and future demand, this indicator is significant in the maintenance of natural rubber demand. The total latex production is determined from the production rate of productive plantations. Total latex production changes dynamically according to the transformation of productive areas. Productive areas can enter a low-productive phase, and some immature areas can enter a productive phase at various points in time. The modification of replanting allocations affects the transformation of productive areas, which in turn influences latex production. Future latex production is determined by current replanting policy, as well as the current composition of plantation areas.

The total latex production also represents the total income that can be generated for governments from every kilogram of latex. This income is significant for some district governments and provincial governments in Indonesia. The total latex production also influences the utilization of primary processors who receive supplies from plantations. This utilization is significant for primary processors as it relates to the ways they plan the future capacity of their factories. Current circumstances reviewed in the case study show how primary processors in North Sumatera are reducing factory utilization owing to the reduction of natural rubber supplies from rubber plantations. To avoid similar situations in the future, the utilization of primary processors need to be considered an important indicator for replanting processes.

Another impact of replanting from the case study investigation is the loss of income for rubber smallholders during the first six years, owing to the immaturity of trees. Currently, however, it is not clear how many rubber smallholders with immature trees exist within the network. As a result, the government faces difficulties in planning types of support for these rubber smallholders. Currently, support can be given in the form of alternative crops to rubber. Rubber smallholders can thus implement an intercropping system in their plantations to generate income while rubber trees are at an immature phase.

From fieldwork observations, replanting was found to reduce natural rubber flow within the network, because it transforms low-productive areas into immature non-productive areas. The low-productive areas still produce latex, but productivity levels are lower than productive areas, while the immature areas are unable to produce latex. If replanting is implemented by many rubber smallholders at a similar time, latex supply from that area might therefore be reduced significantly. The accumulation of stocks of natural rubber for each player in the supply network can help us to gain a clearer picture of the natural rubber flow within the supply network. Stock levels refer to the sum of latex that is collected and retained by players within a certain period. Using this indicator, we can examine reductions in material flow resulting from replanting activities.

The next indicator comprises income generated by key players. Stock levels can be used to predict the income of these players within the supply network. The income of key players is calculated from the total amount of latex transferred between players, multiplied by the daily latex price. For example, the income of rubber smallholders is calculated by the total latex sold to village supplier, multiplied by the price of latex when it is sold. As replanting can reduce the flow of material between key players, the incomes of key players can be subsequently affected. Using this indicator, the impact of replanting on the income of key players – particularly the income of suppliers – can be observed.

5.2.2 Indicators for environmental dimensions

The production of natural rubber also has an environmental impact. Natural rubber has both positive and negative effects on the environment (Blagodatsky et al., 2016). Positive impacts are seen in the ability of rubber trees to absorb carbon dioxide, which is toxic for humans, and in its ability to retain carbon in all parts of the plant, rendering roots, trunk, leaves, and branches effective carbon stocks (Petsri et al., 2013). The negative effects of natural rubber production are generated by cultivation activities like fertilizer treatment, the application of herbicide, and burning processes that take place during replanting. These activities emit greenhouse gases to surroundings (Jawjit et al., 2010). To gauge these environmental impacts, several indicators have been identified, including emissions from fertilizers, emissions from replanting, and emissions from herbicides, carbon sequestration, and carbon stocks.

According to Jawjit et al. (2010), for productive and immature plantations, emissions are mainly produced by fertilizers and herbicides. Further emissions are caused by burning processes during replanting. The implementation of fertilizer and herbicide is influenced by several factors, including the behaviour of rubber smallholders and the composition of plantation areas. As such, emissions dynamically change the composition of plantation areas. Furthermore, emissions from replanting depend on the total replanting conducted by rubber smallholders. Using these indicators, stakeholders can ascertain emissions from rubber plantations within a certain period.

A further emission from the natural rubber supply network comprises greenhouse gas emissions that are emitted by vehicles during the distribution process (Jawjit et al., 2010). Since the distribution process use variously sized trucks, cars, or motorcycles that release greenhouse gases, this impact can be predicted by examining the total distances travelled by each supplier in the distribution of latex. Using this indicator, total emissions during the distribution process can be predicted.

Carbon sequestration and carbon stocks are important indicators for measuring the total amount of carbon absorbed and stored by rubber plantations. However, the ability to store carbon is different for immature plants and productive plants (Petsri et al., 2013). The ability to store carbon increases in parallel with the age of the rubber plant. Furthermore, carbon stocks are also found in latex. As a result, an estimation of latex carbon stocks can be made from total latex production. The sum carbon stock in the supply network can be calculated by taking into account carbon stocks in immature land, carbon stocks in productive land, and carbon stocks in latex. However, the total carbon stocks in the supply network change dynamically according to the composition of the plantation area. Replanting is one factor that can reduce the ability of a supply network to store carbon. Stakeholders can evaluate replanting plans based on the reduction of carbon stocks at a future time.

5.2.3 Indicators for Social Dimensions

The natural rubber industry, rubber plantations in particular, has a beneficial impact to social communities across supply networks. Increases in the price of latex are found to generate income improvements in several areas, including China (Fu et al., 2017), India, Sri Lanka (Nath et al., 2013), and Indonesia (Syarifa et al., 2016). The industry has proved to absorbs many different typres of labour within the supply network. In Indonesia, the industry supports over five million families. From rubber smallholders with plantations, to tappers as key agents in sourcing latex from rubber trees, and suppliers delivering latex to primary processors, all are examples of people involved in the upstream natural rubber supply network.

Several indicators for social dimensions can be identified, including the population of rubber smallholders, the population of tappers, and the population of suppliers. The smallholder population can change dynamically owing to the phenomenon of crop switching. Since the majority of rubber smallholders depends on income from plantations, rubber smallholder population also reflects the total of rubber smallholders’ dependents that also rely on income from rubber plantations. Replanting is a strategy for maintaining the population of rubber smallholders.

The population of tappers changes on the basis of the composition of plantation areas. The allocation of replanting has a direct impact on the population of tappers, by reducing the total productive area. Plantation areas that are replanted remain low-productive for the following six years. This means that tapper services are no longer required in this type of plantation. Based on field observation, the majority of tappers live near plantations. Some tappers’ livelihoods depend on the profession, particularly those who do not have another profession. Some tappers use the profession as an additional job. Replanting activities reduce the absorption of tappers' surplus labour. As a result, many people lose their jobs and incomes while plantation areas are in immature phases. Stakeholders need to consider this fact in designing replanting plans for specific areas and districts.

Other players affected by replanting include suppliers. Replanting reduces current latex production for a following six years. Replanting therefore reduces the total amount of latex supplied within the network. As a result, suppliers' profits also reduce significantly, in turn diminishing the population of suppliers. Field observation has illuminated this phenomenon. Numerous village suppliers in the North Sumatera Province have pointed out that the population of village suppliers in their village has decreased compared with circumstances ten years ago. A similar trend occurs for district suppliers whereby many have stopped their operations owing to reduced natural rubber supply in the North Sumatera Province.

There are subsequently three categories of supplier affected by latex production, including the population of village suppliers, the population of district suppliers, and the population of traders. Using these indicators, stakeholders can evaluate the reduction in supplier populations as an impact of decreased latex production causing by replanting. Stakeholders can use these variables in considerations around replanting in a given district or area within the supply network.

5.3 Strategic Planning Tool for Formulating Sustainable Replanting Policies

The assessment of impacts and their trade-offs comprise important steps in the process for formulating sustainable replanting policies. In order to carry out these processes, appropriate tools for assessing replanting and providing trade-offs are required. This section presents a strategic planning tool for integrating sustainability goals within the formulation of replanting policies. The tool has been developed as part of this research.

This section is divided into five sections. Section 5.3.1 presents a design for requirements in the selection of appropriate tools to support the integration process. Following this, the system architecture of the strategic planning tool is delivered in Section 5.3.2. This is followed by an outline of the sustainability assessment method in Section 5.3.3. This section is divided into two sub-sections. In sub section 5.3.3.1, a system dynamics model is presented, while in sub-section 5.3.3.2, an agent-based simulation model is introduced. Section 5.3.4 presents the trade-off and optimisation method for determining optimum replanting. This section is divided into two sub sections. Sub-section 5.3.4.1 introduces a composite indicator model, and sub-section 5.3.4.2 presents a dynamic programming model.

5.3.1 Design of Requirements for Selecting Appropriate Tools

This section outlines the design of requirements for selecting appropriate tools in the construction of the strategic planning tool. The requirements are identified from a literature review. Factors identified in the work of Sala et al. (2015) and Kelly et al. (2013) were used for the selection of appropriate tools. These requirements were then linked with the advantages and disadvantages of recent tools. Table 5.3 shows the relationship between factors, requirements, and implications for tools.

Table 5.3 Requirements for the Selection of Appropriate Tools for Assessing Sustainability and Providing Trade-offs

Factor	Requirement	Implication for Tools
Model purpose or assessment purpose	To predict the impact of rubber replanting on the current rubber supply, future rubber supply, and other sustainability impacts, by gauging the life cycle of rubber plantations and key players' behaviour, and to define the optimum replanting policy in the supply network by providing trade-offs between replanting impacts.	• Hybrid simulation models were selected to assess the impact of replanting, owing to its ability to generate long term impact and to gauge a complex system • Composite indicators were selected to ascertain trade-offs in replanting impacts, and dynamic programming was selected to determine the optimum allocation of replanting based the latter's impacts
System conceptuali sation	The proposed model is expected to capture the life cycle of the rubber plantation. The life cycle of the rubber plant influences natural rubber production and its distribution. Another entity gauged is the behaviour of key players across supply networks, since this affects the material flow of the supply network. Replanting is an essential point in the life cycle of rubber plants that is influenced by the behaviour rubber smallholders. This variable is important and must be included in the model.	• System dynamics was selected to capture the dynamic of natural rubber production and its distribution system, owing to its ability to capture the dynamic change of systems. • Agent-based simulation was selected to capture the behaviour of key players owing to its ability to gauge behaviours of agents.
Boundary-oriented-ness	To define the optimum allocation of replanting based on the impact of replanting in the supply network, in order to support the development of replanting policies	• Replanting allocation is the independent variable that is manipulated in order to achieve several targets of indicators

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Table 5.3 *Continued*

Comprehensiveness	The proposed tool is expected to generate the impact of replanting on the three dimensions of sustainability, and to map trade-offs between these three dimensions of sustainability simultaneously.	• System dynamics and agent-based simulation selected to generate impacts of replanting on three dimensions of sustainability in the supply network • Composite indicators were selected to generate trade-offs between three dimensions of sustainability
Integrated-ness	The proposed tool is expected to define optimum replanting by considering impacts on the three dimensions of sustainability in the supply network	• The integration of sustainability assessments and the trade-off model is required to achieve the optimum replanting
Scalability	The proposed models are expected to generate impacts at aggregate and individual level, since replanting is found to have an impact to current supply (aggregate level), and smallholders' and suppliers' income (individual level). In terms of time scale, to gauge the life cycle of rubber plants, a yearly basis is used, while a daily basis is applied for capturing the material flow of supply network.	• System dynamics was selected to generate impact of replanting at aggregate level (upper level) while agent-based simulation was selected to generate the impact of replanting at an individual level. • System dynamics was set at a yearly basis, while agent based simulation was set at a daily basis
Stakeholder involvement	Stakeholders are expected to be involved in an experiment to determine a replanting scenario, as well as to determine the weight of indicators and sustainability dimensions in the trade-off process.	• Stakeholders are involved in setting the parameters for system dynamics, agent-based simulation, and composite indicators.
Strategic-ness	The proposed model is expected to support strategic decisions to allocate rubber replanting	• The proposed planning model is used to define optimum replanting allocation for the future (1-10 years)
Transparency	The proposed model should be open to accepting data from the real world, including the setting parameters of models	• System dynamics, agent-based simulation, and composite indicators use real-world data as their initial data.
Type of data available	Data available includes that for total productive, immature, low-productive area, as well as total rubber smallholders. For qualitative data, the behaviour of key players is narrated based on information from interviewing relevant stakeholders and key players.	• System dynamics and agent-based simulation is adjusted to ensure that available data can be used in the experiment.

Based on the Table 5.3, hybrid simulation models of system dynamics and agent-based simulation were selected as integrated assessment tools for assessing replanting impacts because they offer the flexibility to gauge the system complexity evidenced in the Indonesian upstream natural rubber supply network. The latter consists of several individual players, including rubber smallholders, village suppliers, and district suppliers.

System dynamics were arranged to represent the life cycle of natural rubber plantations, while agent-based models were designed to represent interactions between players within the supply network. System dynamics were proposed to ascertain the accumulation impacts of replanting at an aggregate scale, while agent-based simulation was proposed to gauge the impact of replanting at an individual scale. By using hybrid simulation models, the scalability requirements could be overcome.

The combination of composite indicators and dynamic programming was put into practice as a trade-off model for replanting. Composite indicators offer the chance for stakeholders to be involved in trade-off processes, as well as offering opportunities to trade-off between the three sustainability dimensions simultaneously. Dynamic programming has been furthermore illustrated as an appropriate method for determining the optimum allocation of resources. Dynamic programming thus presents an effective opportunity in supporting the allocation of replanting within the supply network.

5.3.2 System Architecture of the Strategic Planning Tool

This section outlines the system architecture of the strategic planning tool that was developed based on the integration of sustainability goals and method selection. System architecture consists of hybrid simulations and performance indicators: a sustainability assessment method to assess the impact of replanting scenarios on sustainability in the supply network, and the combination of composite indicators and dynamic programming as a trade-off and optimisation method. Hybrid simulations are deployed to ascertain sustainability impacts for the replanting scenarios of each area or district. System dynamics generates aggregate impacts for the district level, while agent-based simulation illuminates the impacts on individual key players within the network. These impacts are subsequently inputted into the trade-off and optimisation method so that optimum scenarios of replanting can be defined for each targeted district. Figure 5.3 shows the system architecture of the strategic planning tool.

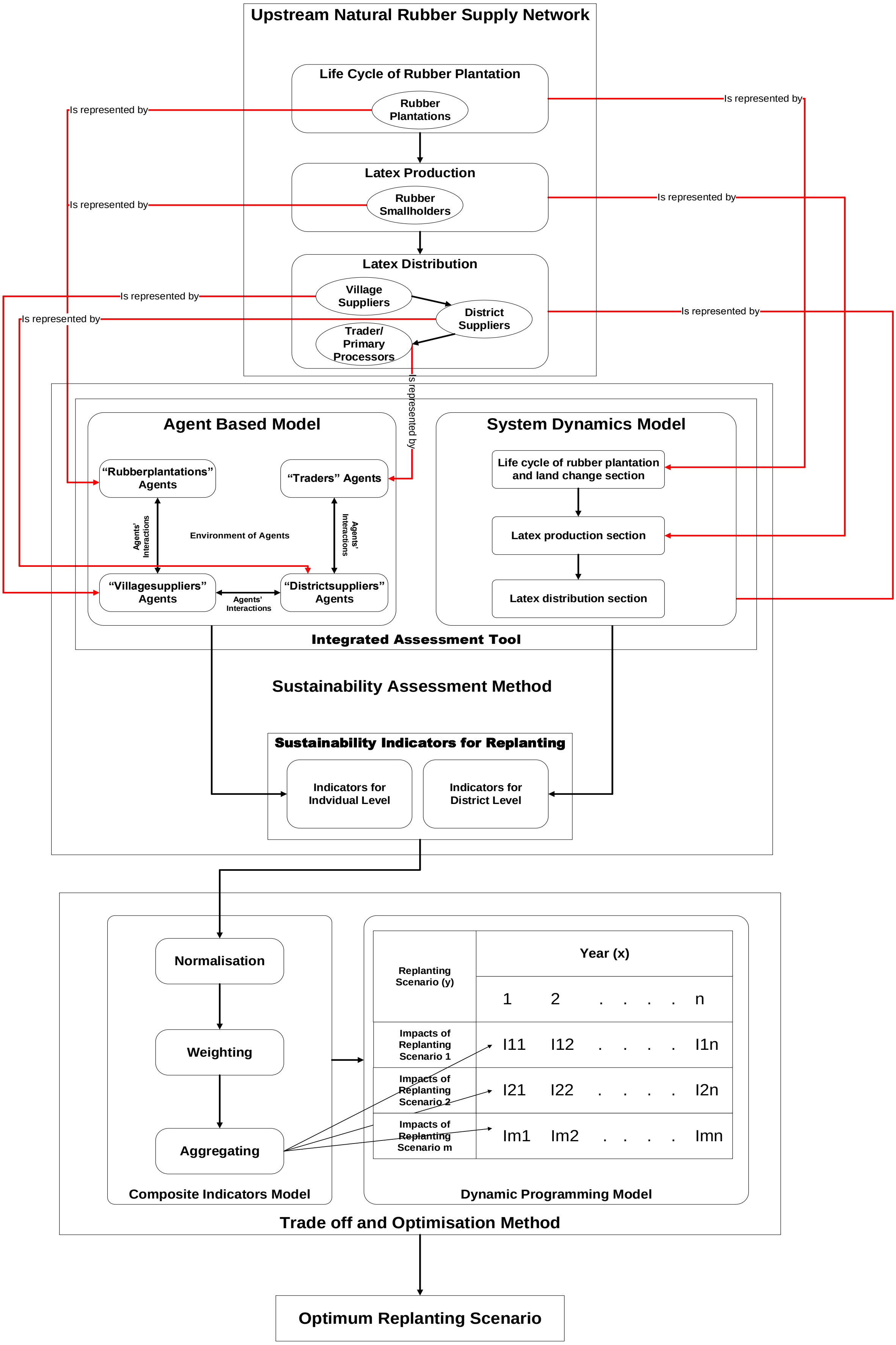


Figure 5.3 System Architecture of the Strategic Planning Tool

The composite indicators model is a key component of integrating the sustainability goals. This approach acts as a bridge in transforming data from simulation models into indexes that then become the main input for dynamic programming. In the composite indicators model, the integration of sustainability goals can be achieved by emphasizing the weight of each dimension and the weight of indicators under each dimension. Using the composite indicators model, policy-makers have the flexibility to determine the importance of each sustainability dimension and each indicator in the planning process.

Composite indicators model also offer a trade-off process between all dimensions and indicators. All sustainability dimensions and indicators are thus considered in the construction of an index. For example, in one district, a reduction in natural rubber supply has been identified. Stakeholders are of the view that production levels are an important indicator requiring management. Subsequently, in the planning process, this indicator is emphasized with a higher weight. Since this indicator is included in the economic dimension, the latter is emphasised more than other dimensions. As a result, the allocation of replanting that generates better production levels can be shown with a higher index.

Dynamic programming is used to define the optimum replanting allocation in the targeted district. This is achieved by comparing the index of each replanting allocation. The outcome of dynamic programming is that replanting allocations are combined for the next several years in the targeted district. The combining of replanting allocations produces the highest replanting impact index in targeted districts.

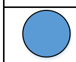
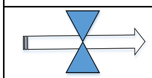
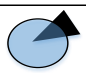
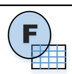
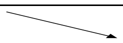
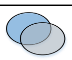
5.3.3 The Sustainability Assessment Method for Assessing Sustainability Impacts of Replanting

The purpose of this section is to introduce the sustainability assessment method developed to assess the sustainability impacts of replanting scenarios at an aggregate and individual level. The sustainability assessment method involved hybrid simulation models of system dynamics and agent-based simulation. To introduce these hybrid simulation models, this section is divided into two sections. Section 5.3.2.1 presents the system dynamics model, and Section 5.3.2.2 introduces the agent-based simulation model.

5.3.3.1 System Dynamics Model of the Indonesian Natural Rubber Supply Network

This section introduces the system dynamics model that was developed as part of the sustainability assessment method to illustrate the Indonesian natural rubber supply network, and to assess the sustainability impacts of replanting. This model was designed to generate the sustainability impacts of replanting at an aggregate level. The system dynamics model was developed based on a conceptual model of North Sumatera's natural rubber production and distribution system (refer to section 4.1.1). The system dynamics model consists of three sections, including the life cycle of plantations and land change section, latex production section, and latex distribution section. This model was developed by translating a conceptual model into a computerised model using stock flow diagrams. This diagram consists of several symbols that reflect entities, variables and parameters. Table 5.4 presents a description of symbols used in the stock flow diagram.

Table 5.4 Description of Symbols used in Stock Flow Diagram

Symbol	Description
	Dynamic variable, this symbol is used to represent variable that change dynamically within the time
	Stock, this symbol is used to represent population. In the model, this can be population of people or area.
	Flow, this symbol is used to represent the flow to/from stock.
	Parameter, this symbol is used to represent static variable.
	Table function, this symbol is used to assign value to dynamic variable.
	Arrow, this symbol is used linking variable, stock, flow and parameters.
	Shadow variable, this symbol is used to reflect dynamic variable in different section.

- **Life Cycle of Rubber Plantations and Land Change Sections in the System Dynamic Model**

This section outlines part of the system dynamics model, which illustrates the life cycle of rubber plantations and land change in the Indonesian upstream natural rubber supply network (see Figure 5.3). The upstream natural rubber supply network consists of thousands of rubber plantations with different ages, scattered across several villages. Some of these plantations are in an immature phase; others are in a productive phase, and other in a low-productive phase. However, over time, this composition changes; some immature plantations become productive and some productive plantations become low-productive. This section is based on a conceptual model of natural rubber plantations' life-cycles, and land changes in the North Sumatera Province (see Section 4.1.1.1). Replanting is a critical point in the life-cycle of rubber plants, and can be represented through a system dynamics model. Replanting transforms low-productive areas into immature areas. As a result, over time, replanting allocations can modify the composition of plantations areas in the supply network. System dynamic models can be used to predict the future composition of plantations, based on current replanting allocations.

The section related to the life-cycle of rubber plantations consists of several dynamic variables, flow variables, and stock variables used to illustrate the dynamic change of rubber plantation areas. Stock variables, including immature plantations, plantations at year 6-10, plantations at year 10-15, plantations at year 15-20, plantations at year 20-25, plantations at year 25-30, low-productive plantations, and old plantations, represent the population of the rubber plantation area in the supply network. The value of a stock variable depends on the initial value, the value of in-flow, and value of out-flow from that specific stock variable. For example, the value of a plantation at year 6-10 depends on the value of an initial plantation at year 6-10, value of entry phase 1, and value of entry phase 2. Value of entry phase 1 depends on the value on table maturation rate 1 and the value of dynamic variable year 6, while the value of entry phase 2 depends on the value on table maturation rate 2 and the value of dynamic variable year 10. The table maturation rate is used to represent the composition of rubber plantation areas in the supply network, while the dynamic variable year (from 1-30) records the new plantation area entering stock.

In the simulation process, the composition of rubber plantation areas is influenced by several variables, including replanting carried out by smallholders, replanting interventions, and land change. Replanting carried out by smallholders represents the total self-supporting replanting done by smallholders who have low-productive land; replanting interventions represent the total plantation area that receives replanting aid from relevant stakeholders. In the real world, smallholders' decisions to replant are influenced by several external factors, including rubber price, palm oil price, rubber seed price, rubber wood price, availability of seed, availability of government aid, replanting cost, and replanting training. To represent this situation, decision models for replanting from Section 4.2.1 are implemented in the simulation model to define the value of the variable relating to for smallholder replanting. The table functions, including rate of rubber price, rate of palm oil price, and rate of seed price, are used to represent the fluctuation in external factors that occurs during the simulation. These functions convey opportunities to adjust the value of external factors during the simulation process. The last variable influencing the composition of rubber plantations is land change. The latter represents the total rubber plantation area that can convert for alternative crop growth in the real world. The value of land change depends on the proportion of rubber smallholders who switch crops. Using a table of switching rates, the proportion of rubber smallholders switching crops can be adjusted during the simulation.

The last important variable affected by changes in the composition of rubber plantation areas is the population of smallholders. In the real world, this population can increasing owing to appearance of new rubber smallholders opening new rubber plantation areas. The reduction of smallholder populations occurs when rubber smallholders decide to switch crops for their plantations. The dynamic variables of smallholder growth rates and smallholders that end their growing activities are used to illustrate the dynamic change in rubber smallholder population in the real world. Figure 5.4 shows the life-cycle of rubber plantations and land change in system dynamics.

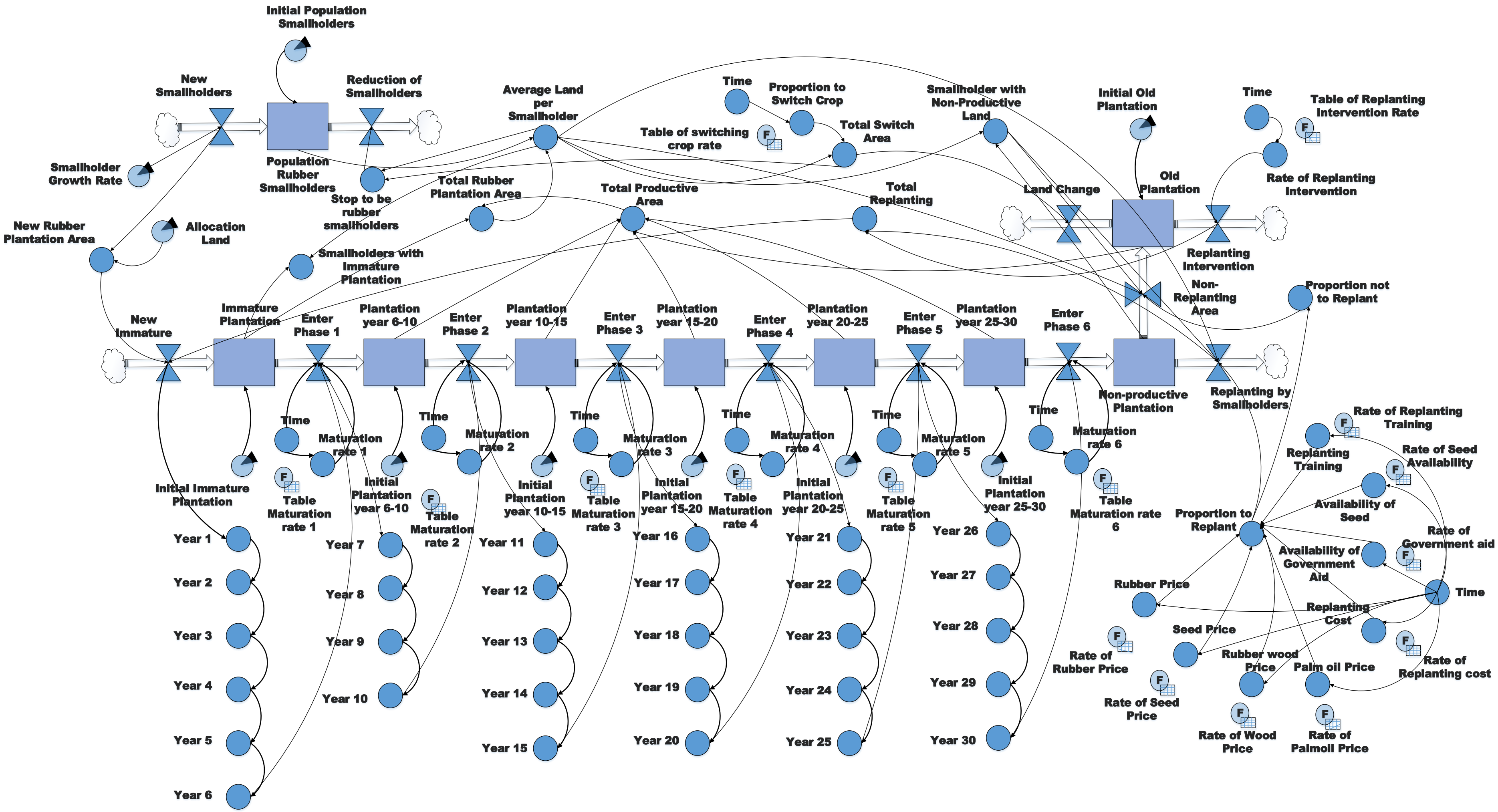


Figure 5.4 Life-Cycle of Rubber Plantations and Land Change in the System Dynamics Model

- **The Latex Production Section in the System Dynamics Model**

This section introduces the part of the system dynamics model that represents the latex production system in the Indonesian upstream natural rubber supply network (see Figure 5.3). This section is developed around the conceptual model of latex production in the North Sumatera natural rubber industry (see 4.1.1.2). The key variables in the latex production section comprise productive areas, production rate, and the population of tappers. Productive areas illustrate the total number of rubber plantations that are able to produce latex in the real world. The productive areas from the life cycle section (see Figure 5.4) are used in the latex production section. There are therefore six types of productive area, including plantations at year 6-10, plantations at year 10-15, plantations at year 15-20, plantations at year 20-25, plantations at year 25-30, and old plantations. In the real world, the production rate of rubber trees can vary according to their age. Rubber trees are expected to achieve maximum productivity at year 15-20, while the lowest productivity is found at old plantations. To illustrate this situation, the production rate for each type of plantation is given, including “prod-rate phase 1”, “prod-rate phase 2”, “prod-rate phase3”, “prod-rate phase 4”, “prod-rate phase 5” and “prod-rate phase 6”.

Another important variable in the latex production section is the population of tappers. In the real world, tappers tap rubber trees to accumulate latex from rubber trees. In the simulation, the ability of tappers to tap rubber plantations is reflected by the variable of tapper performance. The total number of rubber plantations covered by the tapper (tapper rate) can be calculated by multiplying the population of tappers with tapper performance. The proportion of the area covered by tappers reflects the total productive area that can be tapped. By using all influential variables, latex production for every phase can be calculated by multiplying the total production area at a given phase with the proportion of the area covered by the tapper, and the production rate at that phase. Total latex production in the simulation comprises the sum of latex production from every phase. In the simulation, the total latex production is then divided into three types, including lump, slab, and sheet. This is to represent the different types of latex in the upstream natural rubber supply network.

The population of tappers can dynamically change in supply network, following dynamic changes in the productive area. To represent this, variables related to tapper growth rate and profession changes are introduced in the simulation. These variables depend on the value of comparisons between the total productive area and the tapper rate. If the comparison value is less than one, new tappers are required. The demand for new tappers is calculated by subtracting the total productive area from the tapper rate then divided by the tapper performance. Contrastingly, if the comparison between the total productive areas with tapper rate is larger than one, then a reduction in the current tapper population is required. The total number of tappers that must be reduced is calculated by subtracting the tapper rate from the total productive area, then dividing it by the tapper performance.

The next important variable in the latex production section is the use of fertilizer. Total uses of fertilizer applied to rubber plantations are calculated from the proportion of rubber smallholders applying fertilizer, multiplied with the average land per smallholder, the total number of rubber trees per hectare, and the fertilizer dose. A decision model for using fertilizer in the North Sumatera Province (see section 4.2.1) is used to calculate the total number of rubber smallholders applying fertilizer to their plantations. This decision model can capture the effects of external factors including rubber price, fertilizer price, the availability of fertilizer, and the impact of fertilizer where it is applied.

The production of latex affects the environment through emissions, carbon sequestration, and carbon stocks. Fertilizers and herbicides are one source of emissions in rubber plantation. The emissions are therefore calculated by multiplying the use of fertilizer with the emission rate from fertilizers, and multiplying the use of herbicides with the emission rate from herbicides. The total amount of carbon dioxide absorbed can be calculated by multiplying the total productive area with the carbon sequestration rate. For carbon stocks, the calculation is divided into three: carbon stock from immature plantation, carbon stock from productive plantation, and carbon stock from latex. Figure 5.5 shows the latex production section in the system dynamics model.

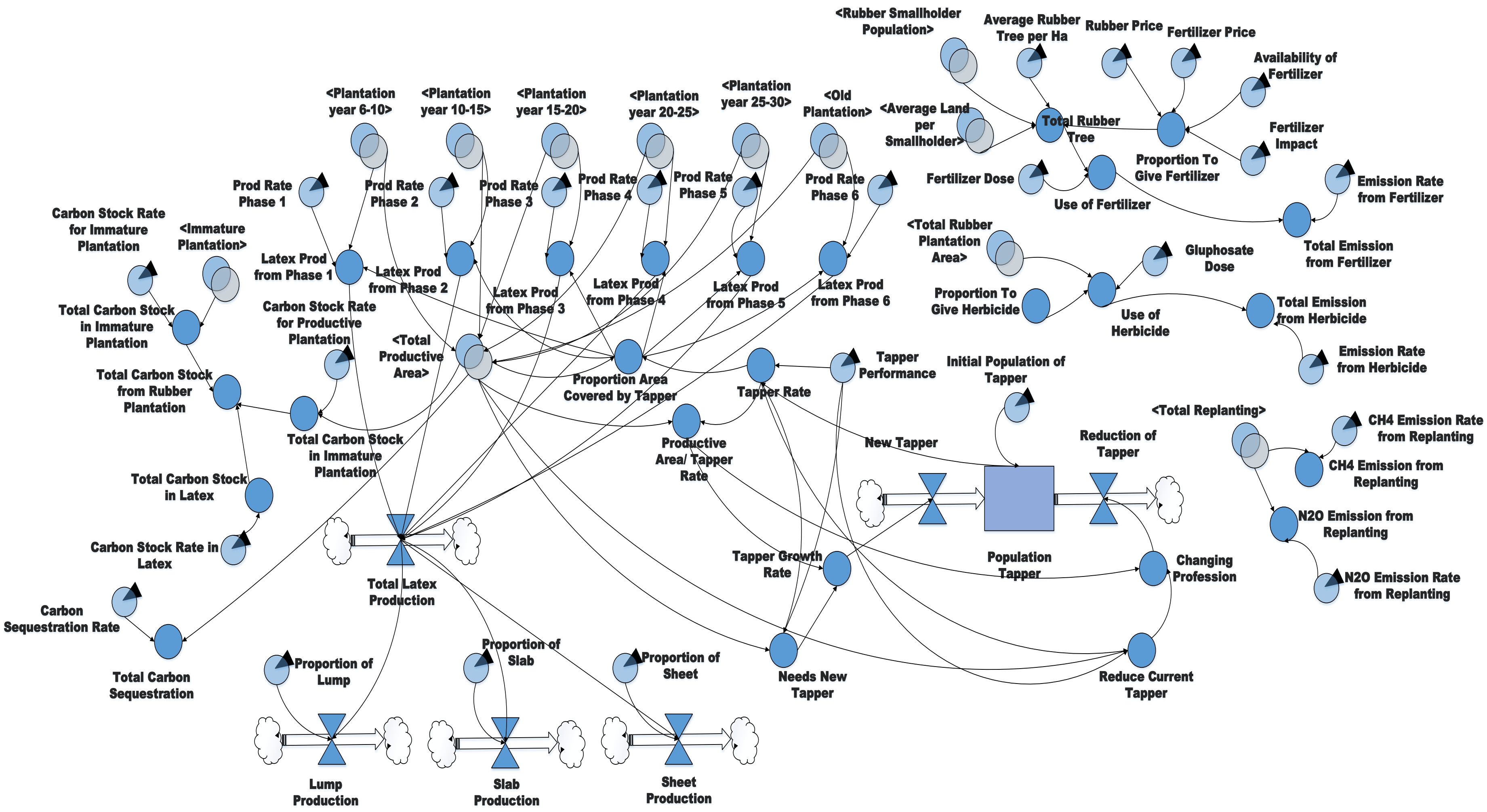


Figure 5.5 Latex Production Section in the System Dynamics Model

- **Latex Distribution Section in System Dynamics Model**

This section introduces the part of the system dynamics model that represents latex distribution in Indonesia's upstream natural rubber supply network (see Figure 5.3). This section is based on a conceptual model of latex distribution in the North Sumatera Province (refer to Section 4.1.1.3). This section begins with the accumulation of total latex produced in different shapes, including in lump, slab, and sheet form, into the variable of latex collected by village suppliers. This variable reflects the total amount of latex needed for supplying to the primary processor.

In the real world, the total latex production influences the population of suppliers. To represent, the variable growth rate and changing professions for all suppliers including village suppliers, district suppliers, and traders are introduced within the simulation model. Variables relating to growth rate and changing profession are active depending on the comparison between the total latex that should be supplied and the actual supply rate from suppliers. Variable relating to supply rates are calculated by multiplying the population of suppliers with the average supply capacity for each supplier. A value of comparison of less than one indicates that total latex production exceeds the supply rate of the given supplier. This indicates that new suppliers are required. Contrastingly, if the value of comparison is higher than one, total latex production is lower than the supply rate. This indicates that numbers of suppliers need to be reduced. The demand for new suppliers is calculated through subtracting total latex production from the supply rate, then multiplying it by the average capacity of suppliers. The number that suppliers must be reduced by is calculated by subtracting the supply rate from the total latex production then multiplying it with the average capacity of suppliers.

Another important variable within the latex distribution section is the utilization of primary processors. This variable relates to the comparison between primary processor capacities and the total latex supplied to primary processors. Primary processor capacity is calculated by multiplying the total number of primary processors operating within the network with the average capacity of primary processors. Figure 5.6 shows the latex distribution section in the system dynamics model.

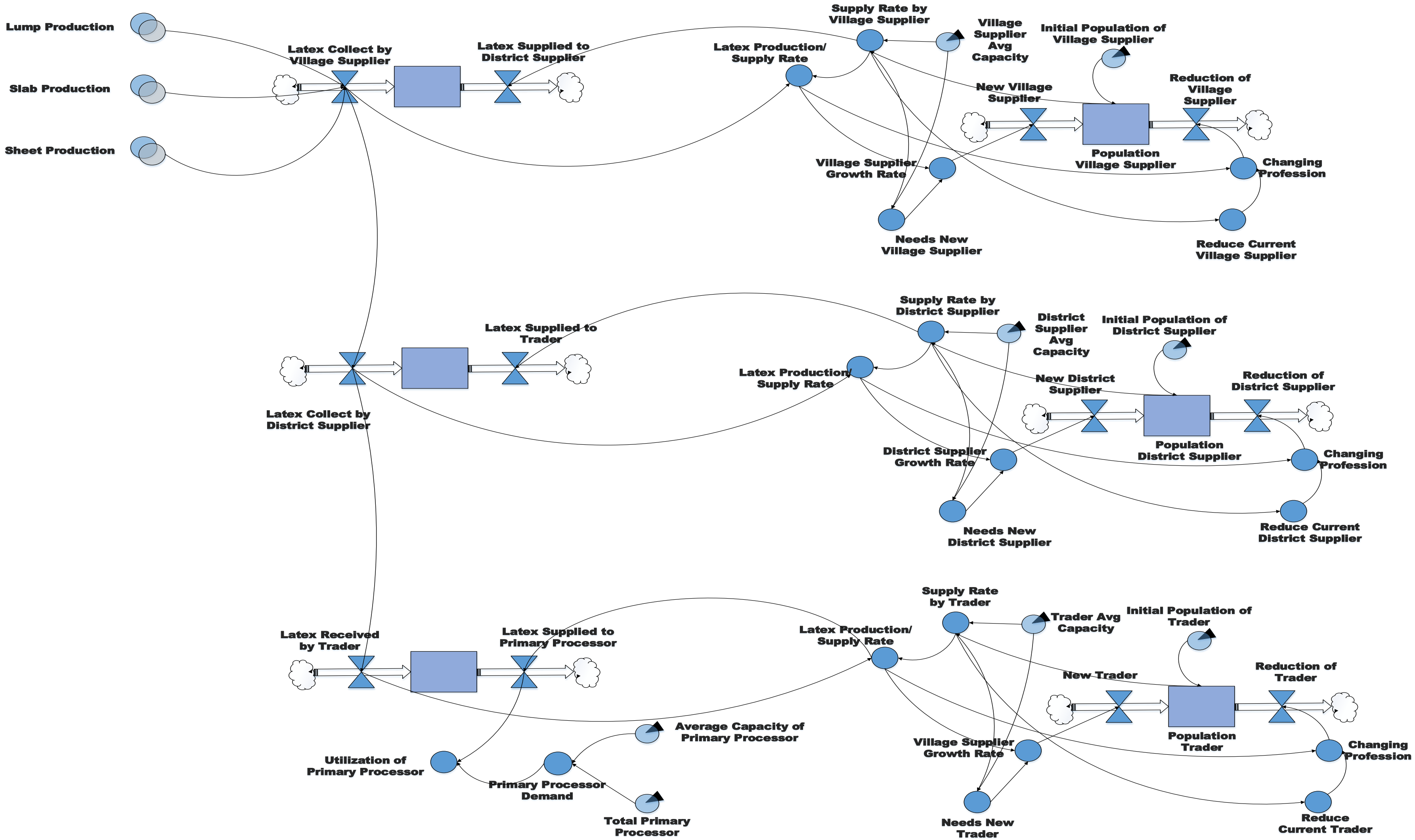


Figure 5.6 Latex Distribution Section in the System Dynamics Model

5.3.3.2 Agent-Based Model of the Indonesian Natural Rubber Supply Network

This section presents the agent-based model developed as part of the sustainability assessment method to represent the Indonesian upstream natural rubber supply network, and to assess the sustainability impacts of replanting on key players' performances across the supply network. Using this approach, the impact of replanting can be predicted at an individual level. Since replanting generates plant immaturity, and therefore obstructs latex production for six years, the reduction of material flows in the supply network occurs. This reduction affects the performance of key players in the upstream natural rubber supply network.

The agent-based model was developed through identifying agents and their behaviours, agents' interactions, and their environment. The structures of key players' operations in the North Sumatera Province (see Section 4.1.2) were used to inform the development of the agent-based model. The agent-based model is divided into three sections: the environment of agents, agents and behaviour, and interactions between agents.

- **The Environment of Agents**

The environment of agents refers to the virtual location of agents in a computerized model developed to represent the position of key players in the real world, e.g. rubber smallholders, village suppliers located at village level and district suppliers or traders located in sub-districts or capitals of districts. The environment of agents is created here using an open street map. This map is developed on the basis of data independently collected by contributors using several tools, including Global Positioning Systems (GPS), aerial photography, and other open sources. The population of agents are scattered across an open street map based on Global Information System (GIS) positions. Figure 5.7 provides an example of environment used in the agent-based simulation.

In Figure 5.7, districts or areas that are focused on are marked with brown layers. The purpose of the brown layer is to divide the district into sub-districts. The population of agents are then divided on the basis of these sub-districts. Not all sub-districts are demarcated in the simulation. Only selected sub-districts that have rubber plantations are highlighted. The flow of materials can be observed via the animation of agents within the map. Sub-districts are marked manually on the basis of official territorial boundaries drawn by the Indonesian Government. The environment in this sense provides information for agents. For example, agents can locate other agents based on proximity.

Figure 5.7 Use of Environment in Agent-Based Simulation (Source: open street map German, Anylogic)

- **Agents and Behaviour**

This section introduces agents within the simulation developed to represent the key players in the Indonesian upstream natural rubber supply network (see Figure 5.3). The main steps in the development of the agent-based simulation comprised the definition of agents and their behaviours. Agents and their behaviours are developed based on the conceptual model shown in section 4.1.2. There are four agents used within simulations, including rubber plantations, village suppliers, district suppliers, and traders.

➢ **The "Rubberplantations" Agent**

Rubber smallholders and their plantations are represented using the "rubberplantations" agent within the simulation. This agent has four parameters, which comprise: area, "warehousecapacity", "cityshape", and "stateshape". Area refers to the total square area of the plantation. This parameter is designed to have a value between 1 and 10. In the real world, smallholders own plantations with a square area between 1 and 10 (see Table 4.6 and Section 4.2.1). "Warehousecapacity" represents the ability of smallholders to retain coagulated latex before selling it to customers. In the real world, some smallholders directly sell coagulated latex after producing it, while others retain coagulated latex until reaching a certain amount (in kg). To gauge this situation, decisions around selling are determined based on the capacity point in "warehousecapacity". Other parameters for rubber plantations comprise cityshape and "stateshape". The parameter "cityshape" is used to identify the Global information system (GIS) position of rubber plantations, while “stateshape” refers to the sub-districts where rubber plantations are located. Figure 5.8 shows the state chart and parameters for rubber plantation agents.

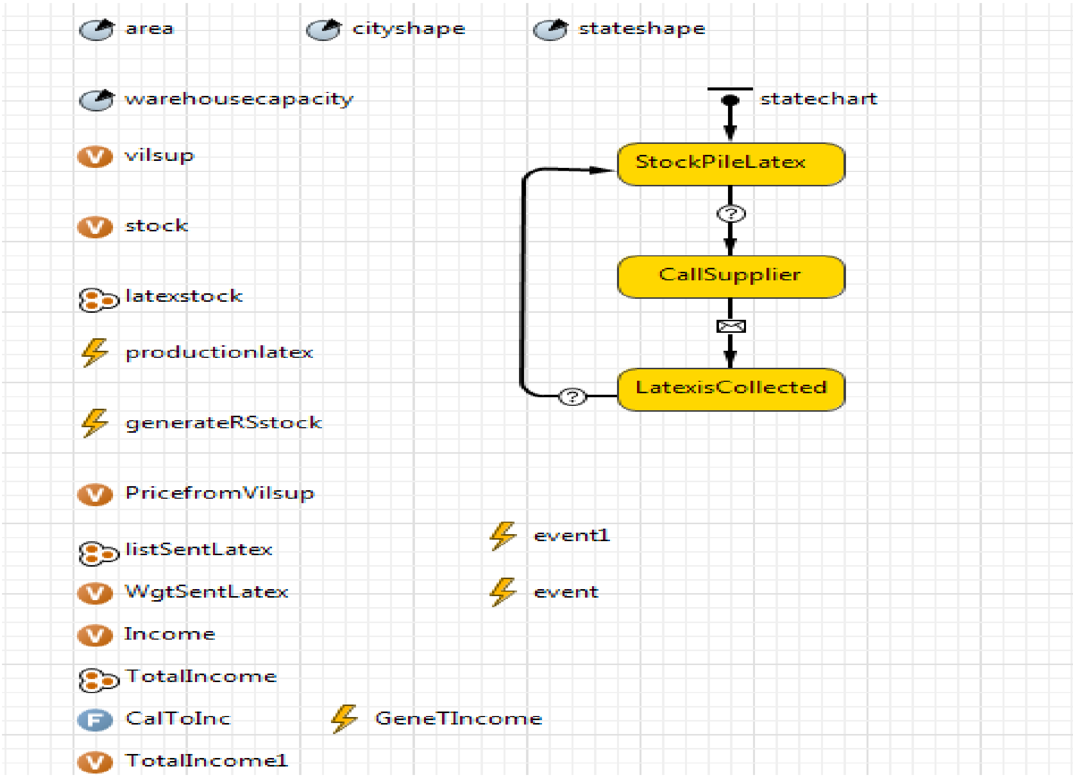


Figure 5.8 State Charts and Parameters for Rubber Plantation Agents

From fieldwork interviews, the activities of rubber smallholders can be divided into three main activities, including the production of latex, contacting village suppliers, and selling latex stock. The behaviour of rubber plantations agents in the simulation is therefore designed to ascertain these activities. State charts are used to capture these activities. From Figure 5.8, it can be seen that the state chart for rubber plantations agents consists of three states, including “StockPileLatex”, “CallSupplier” and “LatexisCollected”. “StockPileLatex” comprises the state of plantations producing coagulated latex. This production increases the total stock. This state then moves to the “CallSupplier” state, when a certain condition has been reached. This condition refers to the value of stock. When stock value reaches certain point from “warehousecapacity”, the agent moves to the following state. At the “CallSupplier” state, the “rubberplantations” agent sends information related to the stock of coagulated latex to the nearest village supplier and requests collection. Then, from the “CallSupplier” state, the agent moves to the “LatexisCollected” state, while the village supplier arrives at the plantation for latex collection. From this state, the rubber plantations agent then returns to the original state, while the stock of coagulated latex collected and made ready for refill through new production. By transferring latex to village suppliers, rubber smallholders receive income that is calculated through multiplying the weight of latex collected by village suppliers (“wgtsentlatex” variable) with the latex price from village supplier (“pricefromvilsup” variable). The “income” variable in Figure 5.8 shows smallholder income from each latex transaction, while the total income variable reflects the accumulation of smallholder income from several transactions within the simulation time.

- **The “Villagesuppliers” Agent**

This agent represents the latex supplier at the village level. In the simulation, this agent collects latex from several “rubberplantations” agents after receiving a request. The “villagesuppliers” agent has four important parameters, including “warehousecapacity”, “vehicle”, “cityshape” and “stateshape”. “Warehousecapacity” refers to the maximum amount of latex that can be bought from “rubberplantations”. “Vehicle” refers to the transportation mode used to collect latex from “rubberplantation”. “Cityshape” refers to the GIS location of “villagesuppliers” agents, while “stateshape” refers to the sub-district where the “villagesuppliers” agent is located.

In the real world, the main activities for village suppliers are the collection of latex from rubber plantations and the sending of requests for district suppliers to collect latex from their locations. To represent these activities, state chart for village supplier agents has been designed, consisting of several states including “standby”, “checkorder”, “checkinventory”, “sendVehicle”, “collectLatex” and “calldissup”.

The state chart for the “villagesuppliers” agent is initiated in a standby position. At this state, the agent waits for the signal to move to other states. An order from the “rubberplantations” agent comprises a signal to move towards the “checkorder” state. All orders from the “rubberplantations” agents are recorded in “listOrder”. The “villagesuppliers” agent takes the first order from “listOrder”. Then the “villagesuppliers” agent checks the availability of the vehicle used to pick up latex. If the “villagesuppliers” vehicle is en route to pick up the order, another order will not be processed. If the order has been collected, the stock value of the “villagesuppliers” agent will be added to the order amount that is collected. An additional state of the “villagesuppliers” agent comprises “checkInventory”. The “villagesuppliers” agent checks their inventory on an annual basis per day. If the stock value reaches a certain point from “warehousecapacity”, the “villagesuppliers” agent sends an order for collection to the “districtsuppliers” agent. The “villagesuppliers” agent will returns to their standby position when the stock has been collected by “districtsuppliers”. Figure 5.9 shows the state chart and parameters for the “villagesupplier” agent.

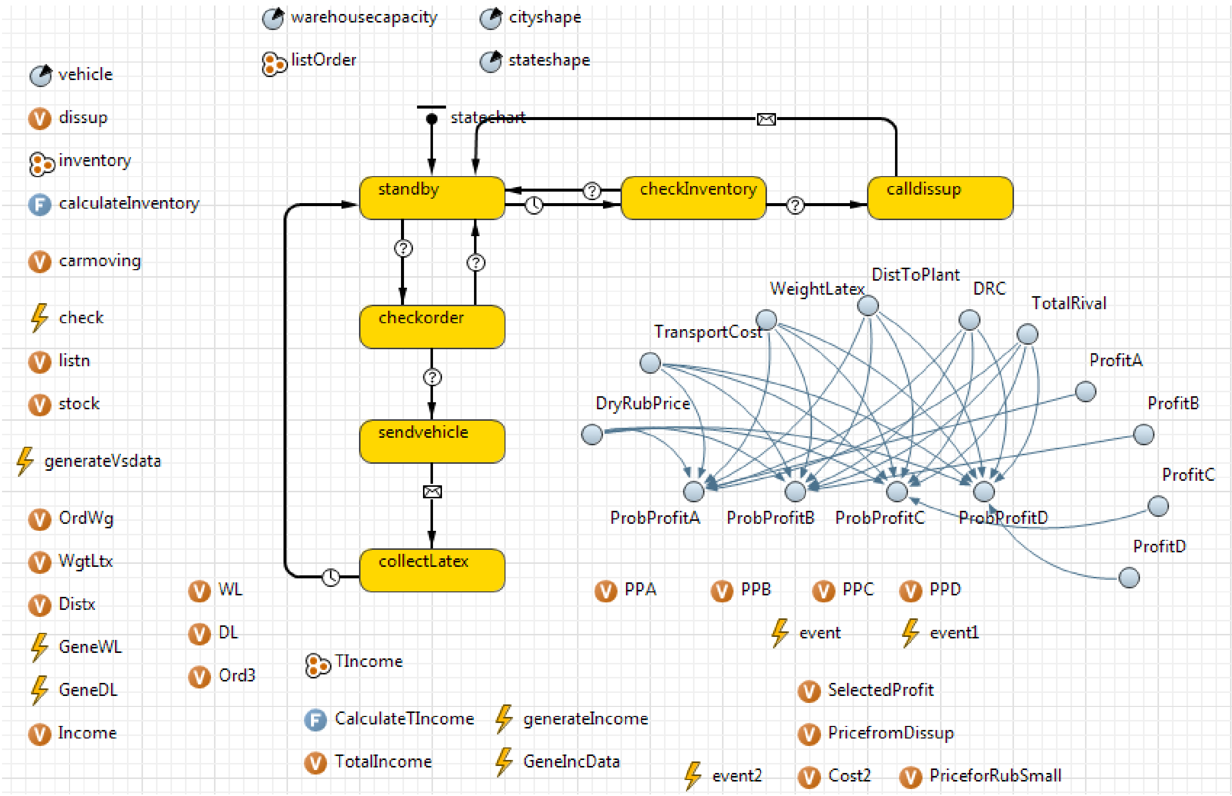


Figure 5.9 State chart and Parameters for ‘villagesuppliers’ Agent

The “villagesuppliers” agent calculates the latex price for the “rubberplantations” agent based on the latex price from the “districtsuppliers” agent, as well as the cost incurred during latex collection, and profit options. The variable “PricefromDissup” shows the information of price from the “districtsuppliers” agent which is sent daily to the “villagesuppliers” agent. The variable “Cost2” reflects the total cost of latex collection, which can vary between “villagesupplier” agents. Profit options are calculated using the Equation 4.3 in Section 4.2.2. Profit is calculated by considering several external factors, including dry rubber price, transport cost, weight of latex, distance to plantation, dry rubber content, and total number of competitors. Using the chosen profits, income for every transaction is calculated by multiplying the weight of latex (“wgtLtx”) with the profit (“selectedProfit”). The variable “TotalIncome” records the accumulation of village suppliers’ income from several transactions.

- **The "Districtsuppliers" Agent**

This agent represents the latex supplier at the district level. The "districtsuppliers" agent incorporates five parameters, including "warehousecapacity", "rubtrad", "truck", "cityshape", and "stateshape". "Warehousecapacity" refers to the maximum latex that can be bought by the "districtsuppliers" agent. The value for this parameter refers to Table 4.11 in Section 4.4. "Rubtrad" comprises the parameter that reflects traders' agents (the primary processor), which in turn comprises a destination for sending latex. The "truck" parameter refers to a mode of transport used by this agent to collect latex from the "villagesuppliers" agent, and to send latex to the primary processor. The "cityshape" refers to the GIS position of this agent in the environment, while "stateshape" refers to the sub-district where the "districtsuppliers" agent is located.

To represent the activities of district suppliers in real world, a state chart for the "districtsupplier" agent is presented. This state chart consists of six states, including "standby", "checkorder", "checkinventory", "sendtruck", "collectlatex", and "sentorubbertrader". In its original position, the agent waits for orders from the "villagesuppliers" agent. This situation is marked as the standby state. This state can be changed to another state if the agent receives an order from the "villagesuppliers" agent or reaches the time for checking inventory. If the order is available, then the agent will check the availability of trucks. If a truck is available (i.e. it is not being used delivery to the "rubbertrader" agent), it is ordered to collect latex from the "villagesuppliers" agent. Stock at this agent will be added whenever the truck returns from collecting latex. Contrastingly, the agent will check the inventory on annual basis. If the current stock reaches a certain point at "warehousecapacity", then the agent will order the truck to send latex stock to the "rubbertraders" agent. This activity reduces stock at this agent. Figure 5.10 shows a state chart and parameters for the "districtsuppliers" agent.

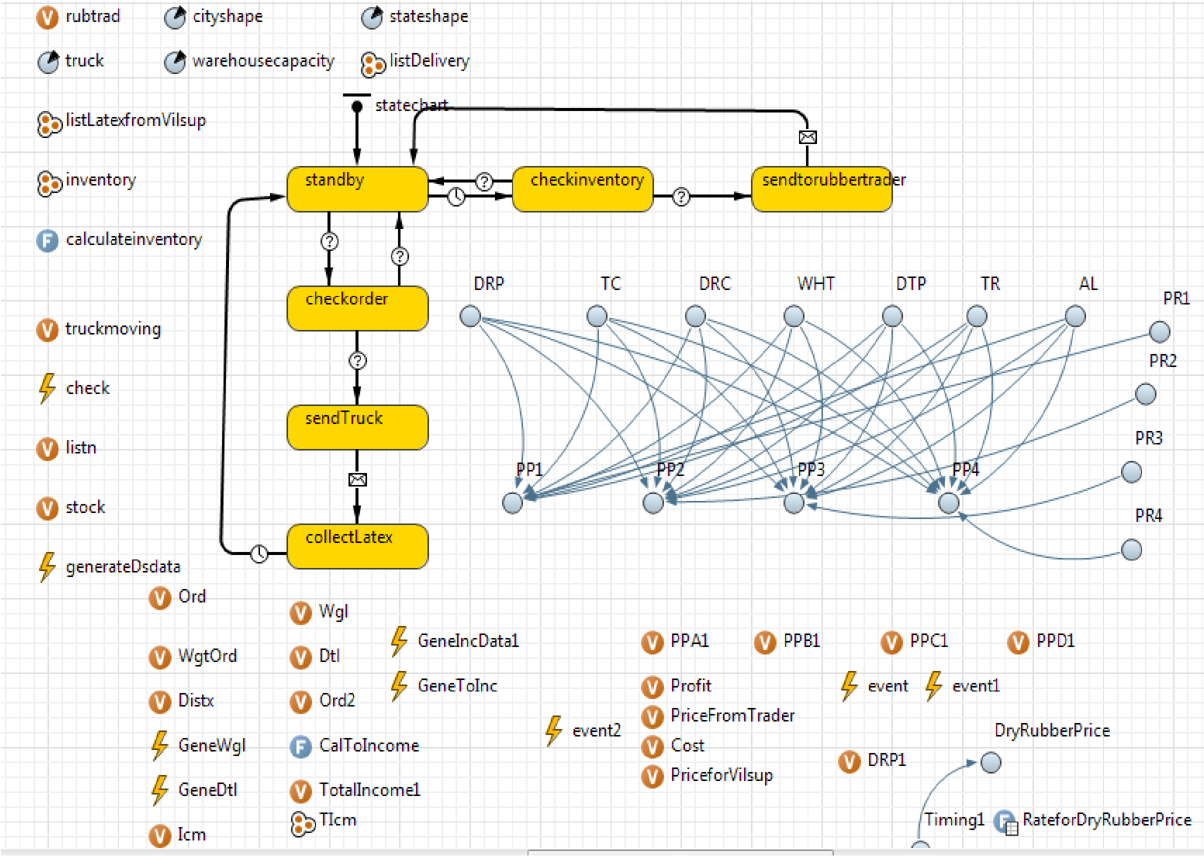


Figure 5.10 State chart and Parameters for the “districtsuppliers” Agent

Determining latex price is one daily activity of the “districtsuppliers” agent. The latex price is calculated based on the dry rubber price from the “traders” agent, as well as costs incurred during latex collection delivery, and profit options. Traders send dry rubber prices to this agent on a daily basis. The variable “PricefromTrader” represents the information from the “trader” agent. The cost of latex collection and delivery to the primary processor varies between district suppliers. Profit options are calculated using Equation 4.4 in Section 4.2.3, by considering several external factors. “PriceforVilsup” is calculated by subtracting “PriceFromTrader” from “Cost” and “Profit”. District suppliers’ income from each transaction with village suppliers is calculated by multiplying the weight of latex (“WgtOrd”) from the village supplier with profit (“Profit”). The variable “TotalIncome1” comprises accumulated district supplier income from several transactions.

➢ **The “Traders” Agent**

This agent represents the rubber trader in the natural rubber supply network, whose function is to buy latex from different district suppliers and receive that latex in the primary processor. This supplier is located at the primary processor. This agent has one parameter: “capacity”. This parameter refers to the ability of the trader to buy latex from district supplier. All of the activities of this agent are described in Figure 5.11.

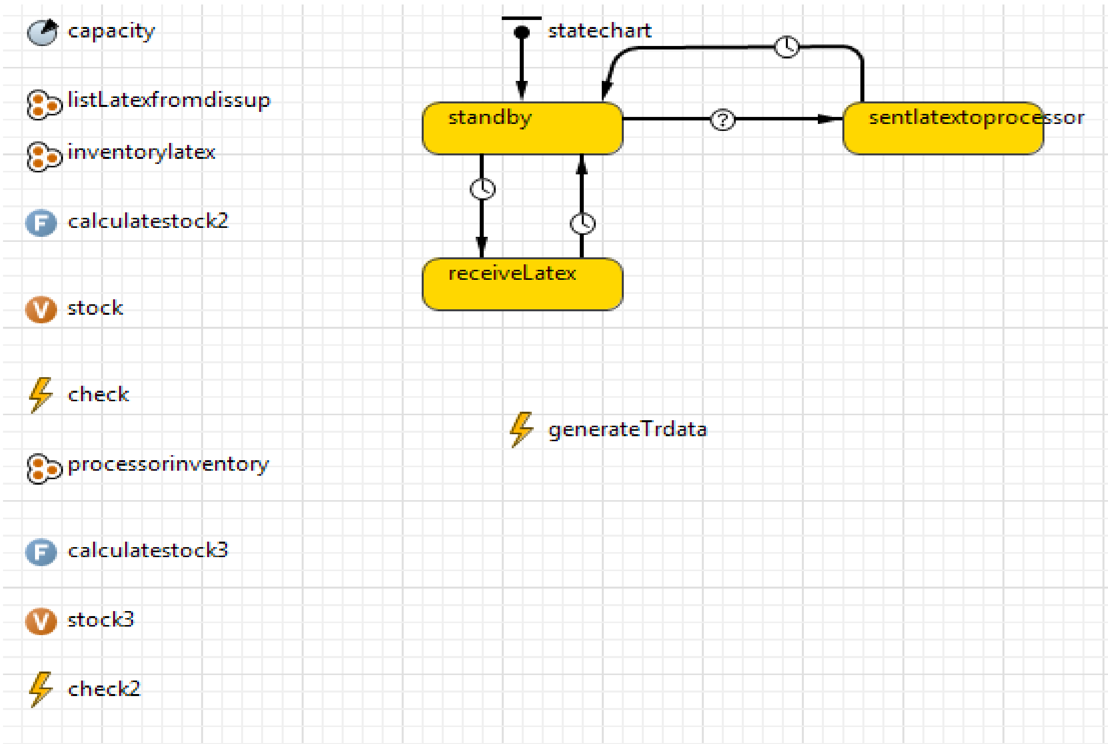


Figure 5.11 State chart and Parameters for the “Traders” Agent

The state chart for the “traders” agent consists of three states: “standby”, “receiveLatex”, and “sentLatextoprocessor”. The starting state for traders is standby. In this state, the agent waits for latex to be sent by “Distruck” and district suppliers. In the real world, the district supplier in one district usually delivers latex to one or two nearby primary processors. When the “districtsuppliers” agent sends the message that latex will be delivered, the “traders” agent moves to the “receiveLatex” state. At this state, the “traders” agent waits for the “distruck” to arrive at their location and begin unloading. After unloading, the stock of this agent will be added. This agent starts to send latex to the primary processor when latex stocks reach a certain point from capacity. When this occurs, the stock level is reduced by the amount that is sent to the primary processor.

- **Agents’ Interactions**

Agents’ interactions in the simulation represent material and information flows between key players in the supply network. In this simulation, each agent establishes a partial relationship with other agents. A partial relationship means that an agent only interacts with certain agents and not with all agents in the network. These interactions occur at certain times that may vary between agents. To describe agents' interactions, a three-dimensional flow model (*pace* Long, 2015) is introduced. The three-dimensional flow model in the supply network consists of material flow, information flow, and time flow. Figure 5.12 shows agents' interactions in supply network.

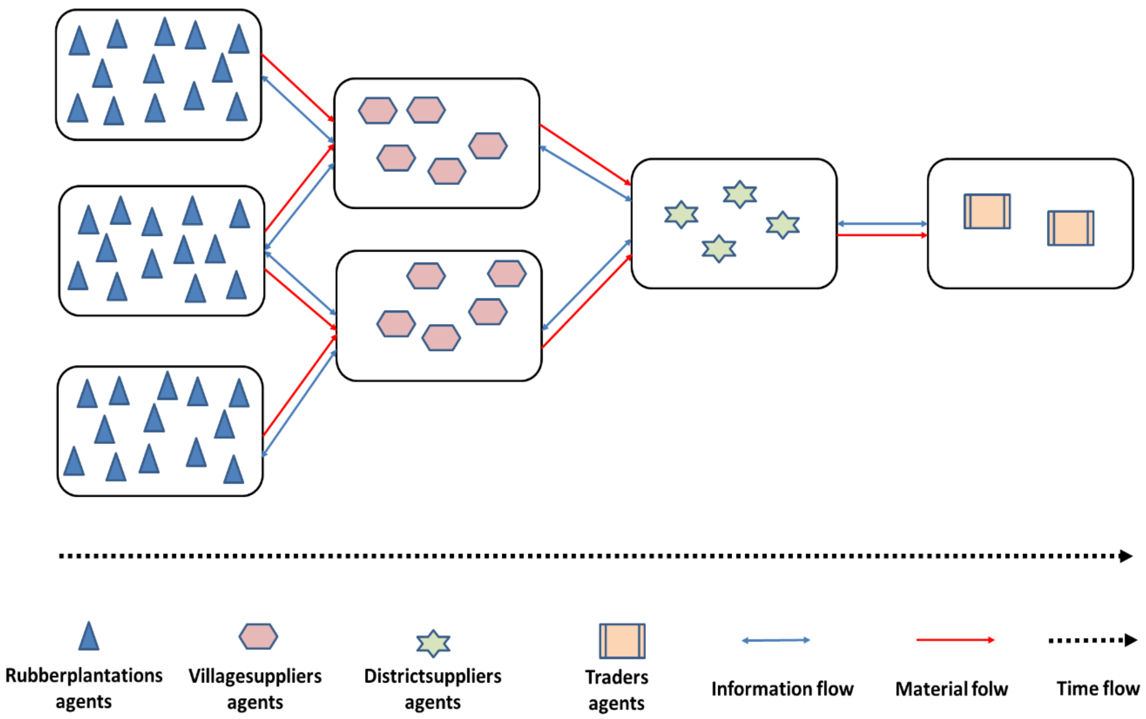


Figure 5.12 Agents' Interactions (Adapted from Long, 2015)

The "rubberplantations" agents send requests for latex collection to "villagesuppliers" after latex stocks in the plantations reach a certain point of maximum capacity. This is marked as information flow from "rubberplantations" agents to "villagesuppliers" agents. If "villagesuppliers" agents are ready to collect, a notification is then sent to the "rubberplantations" agent. Material flow occurs when latex from "rubberplantations" agents is collected and added to stocks at the "villagesuppliers" agent.

The information flow between "villagesuppliers" agents and "districtsuppliers" agents occurs when the order for latex collection is sent to the "districtsuppliers" agent. The order is sent when the stock at the "villagesuppliers" agent reaches a certain point. After receiving the order, the "districtsuppliers" agent will record the order in a list. When this order is ready, the "districtsuppliers" agent sends a notification for the collection of latex. Material flow to the “districtsuppliers” agent occurs once latex is collected. An additional information flow is related to rubber price. “Trader” agents will send dry rubber prices to every “districtsuppliers” agent on a daily basis. This information is then used by this agent to calculate the latex price at the district level. The “districtsuppliers” agent then sends the latex price to the “villagesuppliers” agents within their network. The information from “districtsuppliers” agents is used to calculate the latex price at the village level by the “villagesuppliers” agents. This information is subsequently transferred to the “rubberplantations” agents within their network.

The interaction between the “districtsuppliers” agent and the “traders” agent is begun when the stock at the “districtsuppliers” agent reaches a certain point of maximum capacity. The “districtssuppliers” agent sends a notification to the “traders” agent that latex will be delivered. Material flow between these agents subsequently occurs. After latex arrives at the “traders” agent position, the latter sends a notification to the “districtsuppliers” agent to inform them that latex has been received.

5.3.4 Trade-Off and Optimisation Methods for Determining Optimum Replanting

This section introduces a trade-off and optimisation method developed to detail trade-offs between replanting impacts and optimum replanting determinants. A composite indicators model and dynamic programming model were both developed as part of this trade-off and optimisation method. To present this method, this section is divided into two sub-sections: Section 5.3.3.1 presents the composite indicators model, and Section 5.3.3.2 introduces the dynamic programming model.

5.3.4.1 Composite Indicators Model

This section presents the composite indicators model that was developed to illustrate the trade-off process between sustainability dimensions and indicators, as well as the replanting impacts in planning for replanting. The composite indicators model consists of three sub-models: a normalizing model, weighting model, and aggregating model. These sub-models are required for processing data and information from different indicators and sub-indicators into one single index. The following summarizes the three sub-models of composite indicators.

- **Normalizing Models**

This section presents normalizing models that were developed to change the unit of indicators into uniform units or indexes, and to link the impact of replanting with the targets of indicators. For example, the latex production indicator uses kilograms (kg) as a unit of quantity, while the population of tappers uses people as a unit. The values in kg and people must be changed into a uniform value for composite indicators. The unit value for composite indicators should be same for all indicators. Two models were developed for normalizing the value of indicators, including maximum and minimum, and distance to reference. Maximum and minimum are used when the target of an indicator has a minimum and maximum value. If there is only one reference as a target of an indicator, a distance of reference is preferred.

Table 5.5 Normalizing Models

Normalizing Model	**Equation**	
Maximum and minimum (Equation 5.2 is applied while indicator has a negative impact)	$N_{i,j,a,b} = \dfrac{V_{i,j,a,b} - V_{i,j,b}^{min}}{V_{i,j,b}^{max} - V_{i,j,b}^{min}}$	**5.1**
	$N_{i,j,a,b} = 1 - \dfrac{V_{i,j,a,b} - V_{i,j,b}^{min}}{V_{i,j,b}^{max} - V_{i,j,b}^{min}}$	**5.2**
Distance to reference (Equation 5.4 is applied while indicator has a negative impact)	$N_{i,j,a,b} = \dfrac{V_{i,j,a,b}}{V_{i,j,b}^{reference}}$	**5.3**
	$N_{i,j,a,b} = \dfrac{V_{i,j,b}^{reference}}{V_{i,j,a,b}}$	**5.4**

Where $V_{i,j,a,b}$ is the value for indicator (i) from the group of sustainability dimension (j) which is an impact resulting from rubber replanting scenario (a) for area/district (b). $V_{i,j,b}^{reference}$ is the reference for indicator (i) under dimension (j) and district (b), $V_{i,j,b}^{max}$ is the maximum value and $V_{i,j,b}^{min}$ is the minimum value for indicator (i) under dimension (j) and district (b).

- **Weighting Models**

This section introduces weighting models developed to assign the weight of indicators and of sustainability dimensions. The weight of sustainability dimensions and indicators illustrates the importance of dimensions and indicators within the planning process. This step offers planners the flexibility of prioritising indicators and sustainability dimensions. Two models were developed to assign weight to indicators and sustainability dimensions: equal weighting and budget allocation process. The equal weighting model is used where no indicators are required for emphasis. If there are indicators requiring prioritisation, a budget allocation process model is used.

- Equal Weighting Model

  The assumption of this method is that all indicators have the same weight. This is a very simple method for assigning weight by dividing 1 or 100% by the total number of indicators or sub indicators. A disadvantage of this method is there is no flexibility for planners to emphasize important indicators. This method sometimes ignores the fact that some indicators must be assigned as more important than other indicators owing to historical and statistical data.

- The Budget Allocation Process Model

  This method requires the participation of experts in assigning weight to indicators and sustainability dimensions. The purpose of this method is to capture specific local requirements that can be identified from current environmental, economic or social conditions and regulations. Experts are people who are able to inform the requirements and details of the conditions of an operation owing to a long history of involvement in those operations. A participatory method such as an analytical hierarchy process can be used to ascertain expert opinion on indicators or sub-indicators. A disadvantage of this method is that the weight of indicators or sub-indicators may not be transferable to other types of industries or regions.

- **Aggregation Models**

This section introduces aggregation models developed to provide trade-offs between indicators and sustainability dimensions. Composite indicators are constructed from a hierarchy of indicators and sustainability dimensions. The value of each dimension is defined from the aggregation value of indicators within a particular dimension. The value of composite indicators is aggregated from the value of dimensions. The poor performance of one indicator can be balanced by the high value-performance from other indicators. Two models for aggregation were developed: a linear aggregation model and a geometric aggregation model.

Table 5.6 Aggregation Models

Aggregation Model	**Equation**	
Linear Aggregation Model (equation 5.5 is used to aggregate the impact of replanting on a specific dimension of sustainability, while equation 5.6 is used to aggregate the impact of replanting on sustainability)	$I_{SI\ j,b} = \sum_{i=1}^{n} N_{i,j,a,b} \cdot w_{i,j,b}$ $w_{i,j,b} = 1$ $w_{i,j,b} \geq 0$	**5.5**
	$I_{sust.impact} = \sum_{j=1}^{n} I_{SI\ j,b} \cdot w_{j,b}$ $\sum w_{j,b} = 1$ $w_{j,b} \geq 0$	**5.6**
Geometric Aggregation Model (equation 5.7 is used to aggregate the impact of replanting on a specific dimension of sustainability while equation 5.8 is used to aggregate the impact of replanting on sustainability)	$I_{SI\ j,b} = \prod_{j=1}^{n} \left(N_{i,j,a,b}\right)^{w_{i,j,b}}$ $w_{i,j,b} = 1$ $w_{i,j,b} \geq 0$	**5.7**
	$I_{sust.impact} = \prod_{j=1}^{n} \left(I_{SI\ j,b}\right)^{w_{j,b}}$ $\sum w_{j,b} = 1$ $w_{j,b} \geq 0$	**5.8**

Where $I_{sust.impact}$ is the composite index that reflects the impact of replanting for area/district (b) and replanting scenario (a), $I_{SI\ j,b}$ is impact of replanting into specific dimension of sustainability(j) for district (b), $w_{j,b}$ is weight of sustainability dimension (j) for district (b), $w_{i,j,b}$ is weight of indicator (i) under sustainability dimension (j) for district (b).

5.3.4.2 Dynamic Programming Model

This section outlines the dynamic programming model developed to determine the optimum replanting scenario. Dynamic programming defines solutions to problems by dividing a problem into sub-problems. Solutions are then generated for each sub-problem gradually and sequentially, until solutions for all sub-problems are generated. Solutions are generated using a dynamic function that follows the objectives of optimization. Based on this description, dynamic programming consists of:

- Stage (x): represents sub problem, which is moved through in generating solutions until the last stage. In this research, stage (x) represents the year when replanting scenario is implemented. For example: 2016, 2017 and 2018. x = 1,2,3,4,...n
- State (y): represents the decision variable related to the problem for each stage. In this research, state (y) represents the replanting scenario. For example: 100 Ha, 200 Ha and 300 Ha replanting scenarios.
  $y = [\ y_1,\ y_2,\ y_3 \ldots\ldots y_m]^T$
- Contribution function: this function can be used to generate the value ($I_{sust.impact}$) for every decision variable (y) at stage (x). In this research, the value for every state is $I_{sust.impact}$ which is generated by simulation models and the composite indicators model (see figure 5.3).
- Transformation function: this function is used to define an optimum value for each stage.

$$f_x^{**}(y_x) = Max\left[I_{sust.impact}(y_{x-1}, y_x) + f_{x-1}^{**}(y_{x-1})\right] \quad \textbf{5.9}$$
$$x = 1,2,3,4, \ldots., n\ (n = number\ of\ years)$$

  $f_x^{**}(y_x)$ is the optimum replanting impact for scenario (y) at stage x. $I_{sust.impact}$ (y_{x-1},y_x) is the replanting impact for replanting scenario (y) at year x. $f_{x-1}^{**}(y_{x-1})$ is the optimum replanting impact for scenario (y) at stage x-1.

- The recursive equation: there are two recurrent processes comprising forward formulation and backwards formulation. In the forward formulation, the process begins from the first stage, while in the backward formulation, the process is started from the last stage. This research uses forward formulation.

The optimum replanting scenario for targeted areas or districts in the supply network can be defined by dynamic programming. To achieve this objective, a single index relating to the impact of replanting allocations is compared through the Bellman optimality principle. Following this principle, the replanting allocation problem is divided into different stages based on targeted years. Separating problems into sub-problems or stages for dynamic programming can be observed in Figure 5.13. The optimum value in the current stage is influenced by the optimum value in the previous stage. As a result, the optimum value in each stage (year) can be determined using the recursive equation (equation 5.9). Figure 5.13 shows the complete elements using in dynamic programming.

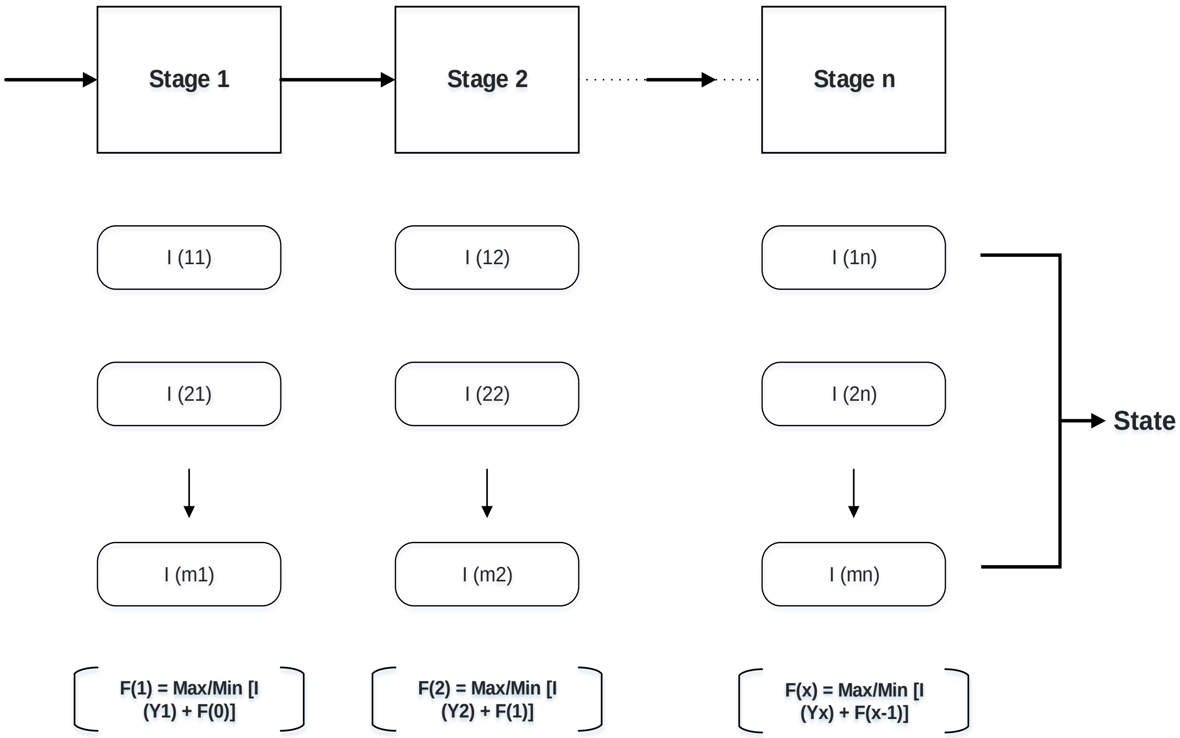


Figure 5.13 Elements in Dynamic Programming Model

5.4 Verification and Validation of the Strategic Planning Tool

This section presents the verification and validation process used for the strategic planning tool. Verification and validation are both necessary improve confidence in using the tool. Validation is necessary to ensure that the established tool produces reliable results and reflects the performance of the system under study, while verification is important for adjusting the system under study. In this research, several verification and validation steps were implemented, including structure verification, the removal of errors from computer models, and operational validation.

The simulation model comprises a main concern in the validation step. This is owing to the fact that the function of simulation models lies in representing the Indonesian upstream natural rubber supply network. The simulation model was created to gauge interactions between entities and relationships between key players in the Indonesian upstream natural rubber supply network, in order to produce essential predictive data. It was therefore necessary to verify the interaction and relationship between variables in the simulation with the real conditions of the natural rubber system, to ensure that the simulation models were producing accurate data.

This study used an adaptation of Sargent's steps for building a verification and validation simulation model (Sargent, 2013). Sargent divides verification and validation steps for simulation models into four categories: the validation of the conceptual model, the verification of the computerized model, operational validation, and data validation. To ascertain these steps, three stages of verification and validation were proposed to ensure that the established tool was producing reliable results.

Initially, the early-computerized simulation models were evaluated using structure verification. The evaluation was run by an expert panel consisting of practitioners, researchers, and academics from GAPKINDO, Sungai Putih Rubber Research Centre, and the University of North Sumatera. A system dynamics flow chart comprises a stock flow diagram showing the relationship between entities in Indonesia's natural rubber system. An agent state chart incorporates diagrams that reflect the behaviours of key players in Indonesia's natural rubber supply network. The system dynamics stock flow diagram and agent state charts were built using the conceptual models in the case study chapter. Evaluations carried out by the expert panel were aimed to check the similarity of the system dynamics flow chart and the agent state chart with the conceptual models of the case study, so as to reflect the real situation of Indonesia's natural rubber system. For trade-offs and optimization models, early equations and functions were verified by testing those equations and functions with manual calculation, in order to confirm the applicability of composite indicators in providing trade-offs for sustainability dimensions and indicators, and the applicability of dynamic programming in defining the optimum allocation of resources.

In the second stage, the activity was focused on the removal of errors from the computer model so that the hybrid simulation models and trade-off models can run smoothly. For the system dynamics models, verification was focused on evaluating the equations to ensure that those equations were dimensionally correct, by checking the balance of the equations. For the agent-based model, verification was focused on checking agent behaviour, with regard to whether it followed the real behaviour of key players. For example, rubber smallholders tap their plantations every two days. For trade-off models, verification was focused on evaluating the model for whether it followed the required steps for composite indicators and dynamic programming. For example, in composite indicators, normalizing, weighting, and aggregating are main steps that should be run sequentially. Verification was carried out to check whether the model had run these steps sequentially.

In the third stage, operational validation was applied by conducting an experiment that used historical data from the case study. In this experiment, simulation models were applied using historical data from five districts to check the applicability of the simulation to different districts. Historical data from 2001 until 2015 was use for comparison with simulation results. However, for the trade-off tool, operational validation was carried out by testing the models with different inputs. This was then continued by comparing results from the trade-off models with results from the manual calculation. The following section focuses on introducing the operational validation results for simulation models, using historical data.

5.4.1 The Operational Validation of the System Dynamics Simulation

The system dynamics model was designed to generate the sustainability impacts of the natural rubber supply network at the aggregate level. Operational validation used historical data validation for this purpose (Sargent, 2013). Five districts were selected as targets of the simulation experiment: Langkat, Deli Serdang, Asahan, Simalungun, and South Tapanuli. Historical data for these districts, dating from 2001 to 2015, were collected from the Indonesian Statistical Agency. Historical data consisted of data relating to the composition of plantation areas (immature, productive and low productive) and the production of latex. Owing to the availability of data, historical data validation was carried out by comparing variables of composition in plantation areas and the production of latex. Before the simulation experiment was started, initial data for the simulation model was inputted. Initial data was collected from historical data. Initial data for simulation models can be observed in Table 5.7. This section focuses on presenting the operational validation results for Langkat district. The operational validation results for Deli Serdang District, Asahan District, Simalungun District, and South Tapanuli District are presented in Appendix D.

Table 5.7 Initial Data for Simulation Experiment

District	Composition of Plantation Area			Distribution of Supplier		
	Immature Area (ha)	Productive Area (ha)	Low productive Area (ha)	Rubber Smallholders (People)	Village Suppliers (People)	District Suppliers (People)
Langkat	3,807	28,263	4,650	22,469	225	22
Deli Serdang	3,422	15,909	6,351	4,816	48	6
Asahan	1,018	8,787	2,820	8,807	88	10
Simalungun	393	12,699	370	9,152	92	4
South Tapanuli	11,142	46,054	2,767	28,147	281	24

5.4.1.1 Historical Validation for Langkat District

Langkat comprises one large district located on the northern side of North Sumatera Province. There are more than 40 thousand hectares of rubber plantation in this district, making Langkat one of the major producers of latex in North Sumatera. Historical data shows an increasing trend in latex production from 2001. This trend has resulted from the growth of rubber plantation areas, particularly in 2005. From this year, the area of rubber plantations in this district tended to be constantly maintained. Historical data also shows that there were few rubber plantations entering low-productive phases from 2009 – less than 300 Ha – although there was a large low-productive area in 2001. Furthermore, historical data shows a substantial amount of immature areas from 2001, with more than 2,500 Ha per year. These immature areas were shown to result from the opening of new plantation areas. This was indicated owing to the low level of low-productive area in this district.

The system dynamics simulation was run to illustrate the dynamics in the productive area and the production of latex for the Langkat District, using initial data from 2001. The simulation results show a similar trend in historical data for the Langkat District. Simulation results illustrate an accretion of productive area. It can be observed in Figure 5.14 that in the simulation results, the productive area increased steadily from around 28,000 hectares in 2001 to around 38,000 hectares in 2015. However, there was a significant error in 2005 when the simulation result was compared with historical data. In the year 2005, in historical data, the productive area jumped significantly from around 28,000 hectares to around 38,000 hectares, while in the simulation result, the productive area remained constant at around 29,500 hectares.

There is no further explanation to support the significant increase in the productive area in historical data. Based on the life-cycle of rubber plantations, the plant cannot be directly productive and must wait 6 years to be productive. In other words, the total productive area will increase depending on the total immature area entering the productive phase. In the historical data, the total immature area in the year 2004 comprises around 3,000 Ha. This amount was less than the total increase of the productive area in the year 2005, which was around 9,500 Ha. The simulation model is not able to capture this sudden change because it follows the life-cycle of the rubber plant. The big leap in historical data in 2005 cannot be processed by the simulation model owing to the total immature area at initial data only coming to around 3,800 hectares. This indicates that the simulation model has succeeded in representing the life-cycle of rubber plantations.

Contrastingly, in terms of latex production, there is not much difference between the historical data and simulation results, although there is a big difference in productive area in 2012. In the simulation result, latex production jumped from around 23,000 tonnes in 2001 to around 35,000 tonnes in 2015, as shown in Figure 5.15. The biggest difference was detected in 2012, at which point there was a significant increase in latex production in the historical data. There was no further clarification for this increase in the historical data. In fact, the production of latex is mainly dependent on the total productive area and the productivity of the area. As can be seen in the historical data, there was no escalation in the productive area for the year 2012. This generates questions as to why the production of rubber in the historical data increased significantly, while the productive area remained constant. This result indicates that the simulation model has succeeded in linking productive areas with latex production.

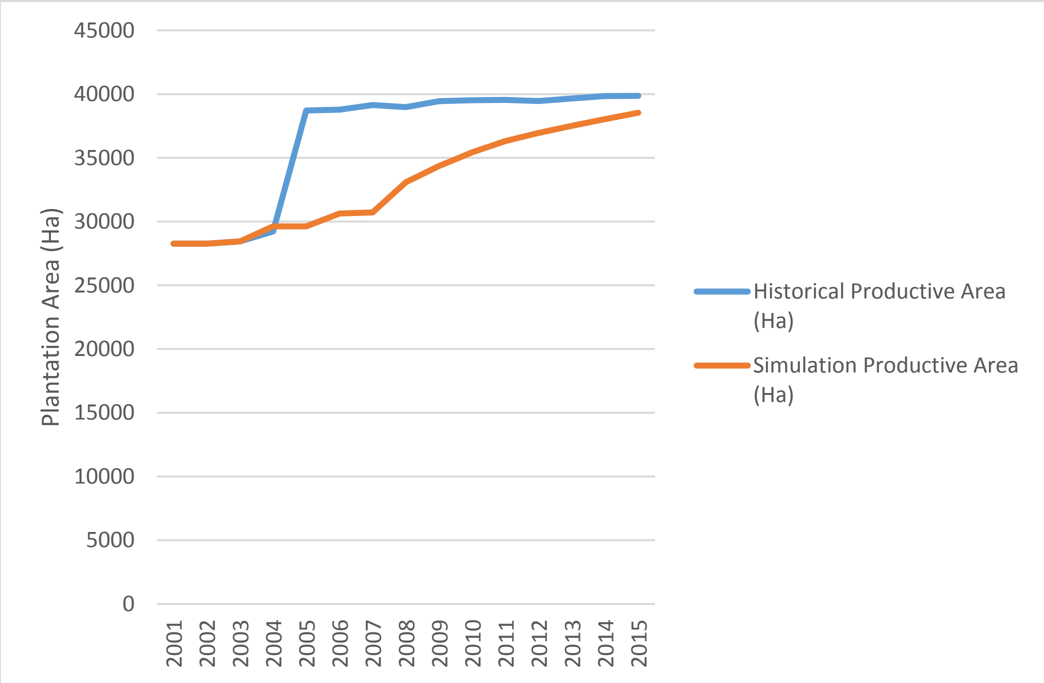


Figure 5.14 Comparison of Simulation Productive Area Data with Historical Productive Data for Langkat District

Table 5.8 Productive Area Difference between Simulation and Historical Data for Langkat District

Year	Productive area Difference (Y)	(Y^2)
2001	0.00	0.00
2002	0.00	0.00
2003	0.00	0.00
2004	410.00	168100.00
2005	9092.00	82664464.00
2006	8144.00	66324736.00
2007	8421.00	70913241.00
2008	5887.96	34668027.88
2009	5084.33	25850387.79
2010	4079.71	16643994.98
2011	3228.16	10421014.09
2012	2496.17	6230886.07
2013	2141.68	4586787.10
2014	1811.73	3282382.86
2015	1323.77	1752356.35
Total Difference	**52120.50**	**323506378.10**
MAE/MSE	**3474.70**	**21567091.87**

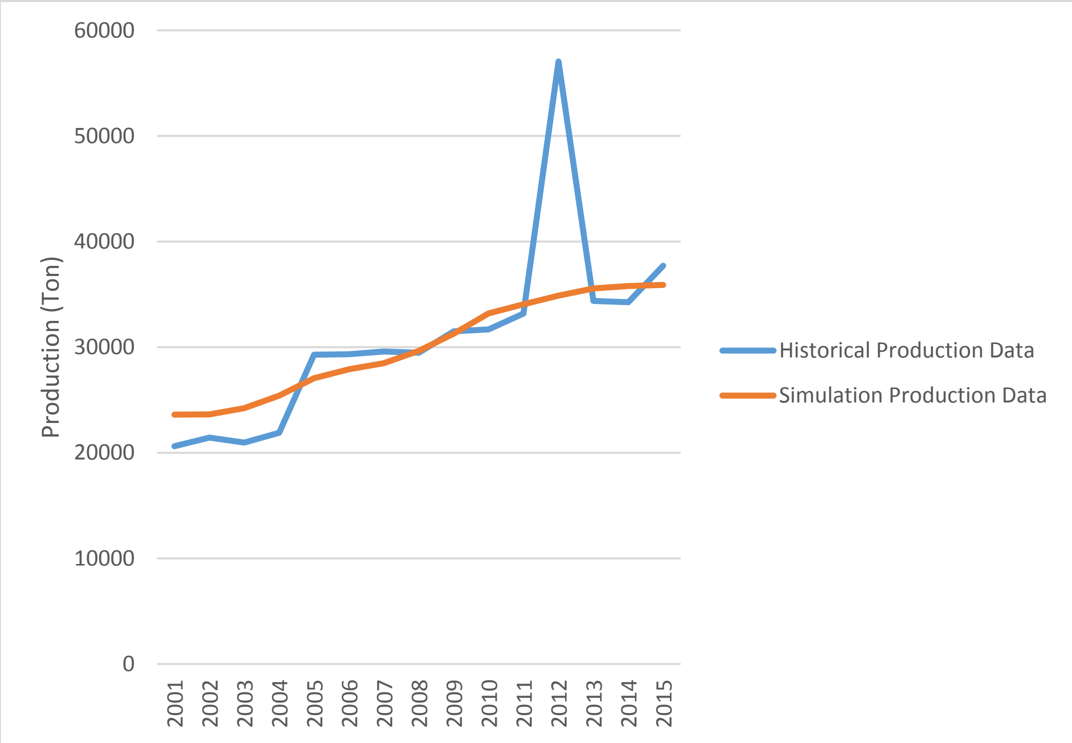


Figure 5.15 Comparison of Simulation Production Data with Historical Production Data for Langkat District

Table 5.9 Production Difference between Simulation and Historical Data for Langkat District

Year	Production Difference (X)	(X^2)
2001	2992.40	8954457.76
2002	2206.20	4867327.80
2003	3258.13	10615419.96
2004	3523.67	12416240.98
2005	2222.02	4937370.00
2006	1428.03	2039271.35
2007	1104.23	1219321.89
2008	188.20	35418.20
2009	226.20	51164.61
2010	1514.72	2294387.74
2011	879.48	773478.49
2012	22165.87	491325835.93
2013	1193.12	1423534.29
2014	1521.34	2314470.37
2015	1817.16	3302063.22
Total Difference	**46240.76**	**546569762.60**
MAE/MSE	**3082.72**	**36437984.17**

5.4.2 Operational Validation of Agent-Based Simulation

Agent-based simulation is designed to generate data for individual key players, while system dynamics is designed to generate data at the aggregate level (e.g. district level). The validation process of agent-based simulation was thus applied by comparing historical data (accumulation of latex) from key players with the results (average latex amounts) from agent-based simulation. However, owing to a lack of historical data available in North Sumatera, data from the discrete choice survey (see Section 4.2) was used as historical data.

Operational validation of agent-based simulation was initiated by determining databases of key player populations. This database was constructed in Microsoft Excel. This database consists of the total population of agents (rubber smallholders, village suppliers, district suppliers, and rubber traders) in each sub-district with reference positions (longitude and latitude). Owing to the limitation of computer hardware and software abilities, the population of agents in the simulation was set up for 10% of the real population in Table 5.7.

The agent-based simulation produced data for rubber smallholders, village suppliers, district suppliers, and rubber traders. This data can be observed in Figure 5.16, which shows the average stock (accumulation of latex) from key players within a certain time. The average stock for rubber smallholders in the simulation was between 50 and 75 Kg. This result reflected the real situation in North Sumatera, in which rubber smallholders owned an area between 1-5 Ha (see Table 4.6). Rubber smallholders could produce 5-20 kg latex per hectare, depending on the productivity of the plantation. The total production of smallholders is therefore between 5-100 kg per Ha/Tapping. It can be seen from Figure 5.16 that there was an increase of stock for rubber smallholders every 24 hours. This indicates that latex was accumulated daily within the network, since rubber smallholders tap their plantations every two days. However, the average stock of rubber smallholders did not return to zero after the stock was supplied to village suppliers. This is owing to the fact that not every rubber smallholder has a similar timescale for tapping in the plantation and for supplying stocks of latex to village suppliers. Stocks for every rubber smallholder will return to zero after the accumulated latex is supplied to village suppliers (see Figure 5.9)

The next result in Figure 5.16 gives the average stock for village suppliers. This supplier accumulates latex from rubber smallholders. According to historical data (see Table 4.11), the accumulation of latex varies for each village supplier between 250 – more than 1,000 kg per week. Usually, village suppliers can supply accumulated latex once or twice a week. It can be seen that, in the simulation, accumulated latex at the village supplier level was between 600-800 kg. This stock can be achieved in 5-6 days, which indicates that accumulated latex is supplied to district suppliers in 5-6 days. In the simulation, every village supplier has a different supply capacity, and thus the timescales for supplying accumulated latex to district suppliers can vary.

For district suppliers, the simulation shows that their average stock is between 6,000 – 8,500 kg. According to historical data (see Table 4.14), the majority of district suppliers supply latex at around 10,000 kg per week. District suppliers accumulate latex from village suppliers, and need 4-6 days to accumulate 10,000 kg latex. In the simulation, district supplier will therefore send latex to rubber traders once a week, depending on the accumulation process. Each district supplier in the simulation has a different capacity. Timescale for the accumulating of latex can therefore vary for each district supplier.

The fourth figure in Figure 5.16 describes the average stock of rubber traders. This figure shows that the accumulation of latex from district suppliers is accepted by rubber traders. It can be seen that the average stock of rubber traders in the simulation came to around 80,000 kg. The interview results from rubber traders indicated that these players could accumulate between 50,000-100,000 kg latex per week (see Table 4.4). Based on the comparison of results in the latex supply process in the simulation and in the real conditions of North Sumatera Province, the simulation process is likely to present the real conditions of natural rubber (latex) flow in North Sumatera, particularly in the Langkat district. However, owing to the database of players in the simulation that is not a synthetic population (i.e. the real population of key players in Langkat district), the result of the simulation will not completely reflect circumstances in Langkat district.

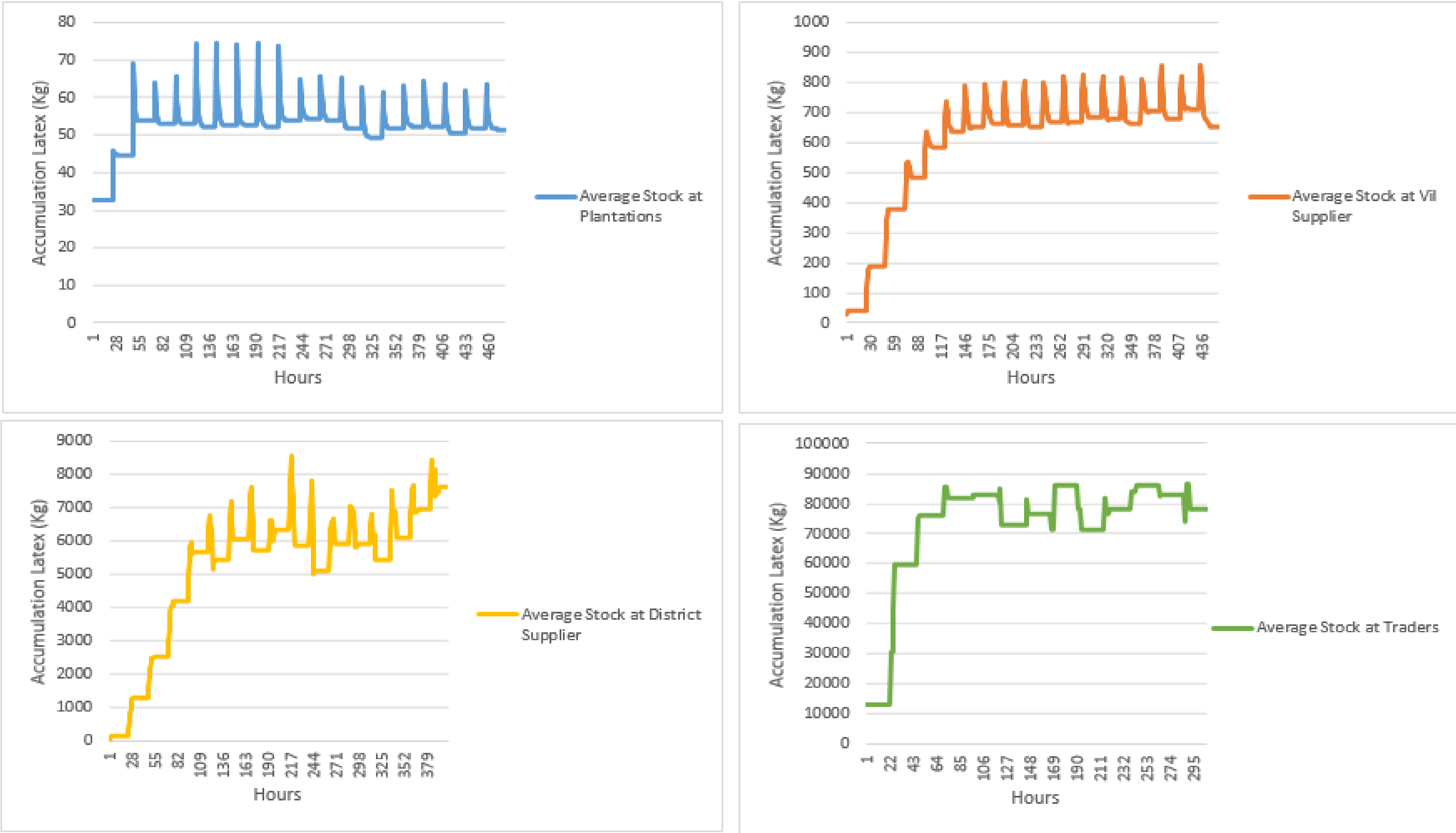


Figure 5.16 Agent-Based Results for Langkat District

5.5 Summary

This chapter has elaborated on an approach for formulating sustainable replanting policies. The approach consists of devising a process, sustainability indicators, and a strategic planning tool. The process and sustainability indicators were based on a literature review and case study investigation. The process highlighted the importance of sustainability assessments and trade-offs around the impacts of replanting in the development of replanting policy. The case study investigation indicated that replanting brings sustainability impacts into the supply network, as well as into key players' performance. To reflect this, sustainability indicators at a district and individual level were identified from a case study investigation and literature review.

The development of the strategic planning tool began by determining requirements for the selection of appropriate tools to support the sustainability assessment and trade-off process. The requirements identified from literature included: model purpose or assessment purpose, system conceptualisation, boundary-oriented-ness, comprehensiveness, integrated-ness, scalability, stakeholder involvement, strategic-ness, transparency, and type of data available. Following this, the system architecture of the strategic planning tool was configured, subsequently consisting of a sustainability assessment method, trade-off method, and optimization method. A hybrid simulation of system dynamics and agent-based simulations was then selected as an integrated assessment tool, and both composite indicators and dynamic programming were selected as a trade-off and optimization method.

This was followed by the development of a strategic planning tool. System dynamics and agent-based simulation models were developed to represent the Indonesian upstream natural rubber supply network and to assess the impacts of replanting on the sustainability of the supply network. Composite indicator models and dynamic programming models were then developed to provide trade-offs around replanting impacts and to determine optimum replanting. The established tool was subsequently verified and validated in three stages, including structure verification, the removal of errors from computer models, and operational validations. A comparison between simulation results and historical data was then reported.

Chapter 6
The Application of Approaches for Formulating Sustainable Replanting Policies in the North Sumatera Natural Rubber Industry

This chapter presents the application of an approach for formulating sustainable replanting policies in the North Sumatera natural rubber Industry. The application of this approach is aimed to demonstrate its feasibility using real-world data and its efficacy with target users. This chapter details the third stage of research activities, which are dominated by conducting simulation experiments for the purpose of the tool's application. Figure 6.1 shows the relationship between the research process and Chapter Six.

As stated in Chapter Four, the North Sumatera natural rubber industry faces a reduction in its natural rubber supply because many plantations have entered a low-productive phase across several districts. Besides the unnecessary impacts generated by this situation, there are opportunities for stakeholders in North Sumatera's natural rubber industry to take advantage of circumstances by managing the replanting of low-productive areas so as to produce a sustainable supply in future. However, this requires effective planning that considers the long-term impact of replanting. The application of an approach for these ends is designed here to support stakeholders in the North Sumatera natural rubber industry in developing replanting policies for several targeted districts in the province. The North Sumatera Provincial Government and Rubber Primary Processors Association are both stakeholders that have a shared interest in sustaining the rubber supply. These stakeholders were thus invited to participate in the application of the tool.

This chapter is developed to present the process for formulating sustainable replanting policies for targeted districts in North Sumatera Province. Figure 6.2 shows the relationship between the process of formulating sustainable replanting policies with sections in Chapter 6. This chapter consists of five sections: Section 6.1 reports on replanting scenarios for targeted districts in the North Sumatera Province. This is followed by Section 6.2, which introduces the sustainability indicators that are used to develop replanting policy. Section 6.3 illustrates the sustainability impacts of replanting scenarios, and Section 6.4 presents the optimum replanting scenarios for targeted districts. In the final section, 6.5, there is a discussion of all the application's results.

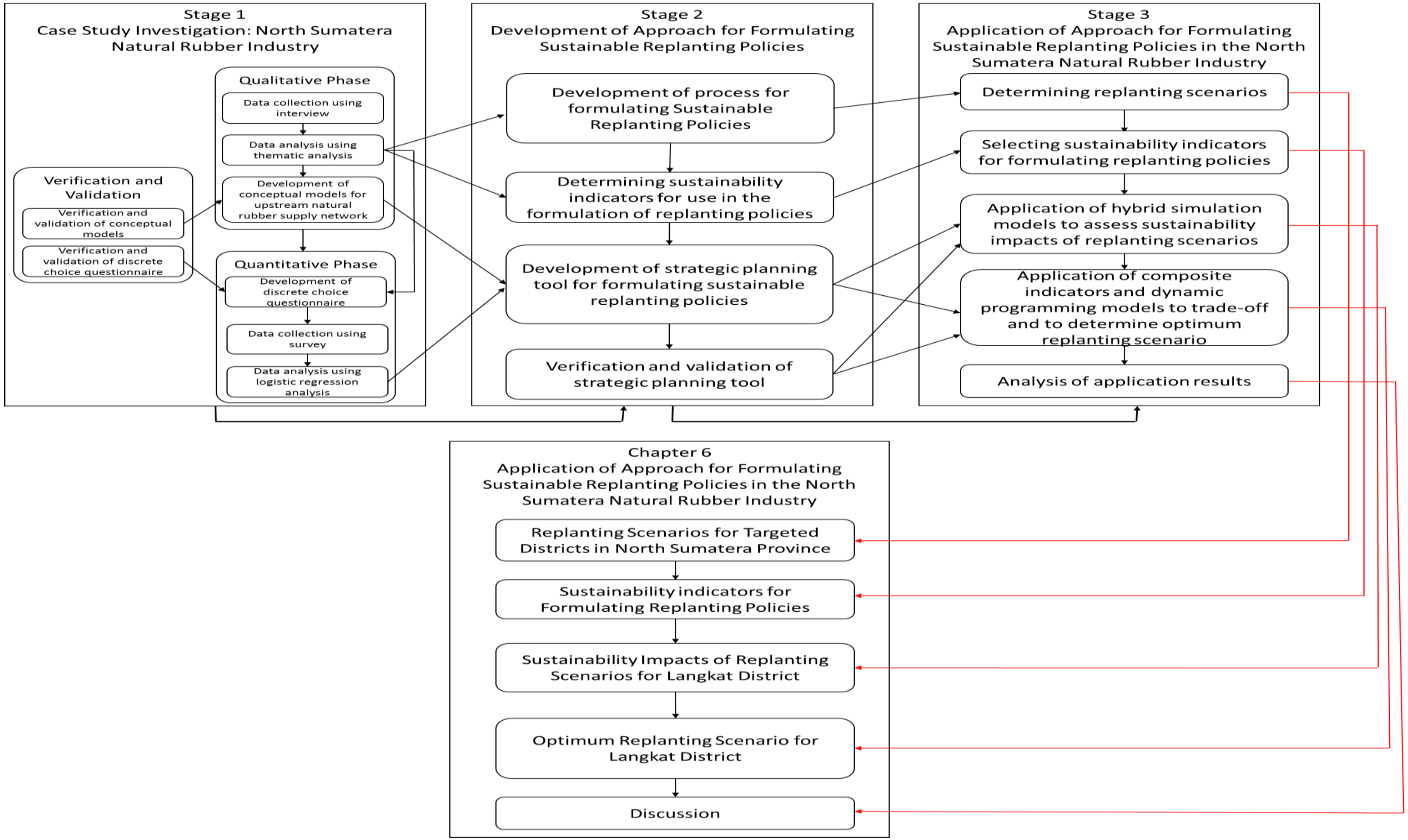


Figure 6.1 Links between the Research Process and Chapter 6

Figure 6.2 The Relationship of the Process for Integrating Sustainability Goals with Sections in Chapter 6

6.1 Replanting Scenarios for Targeted Districts in North Sumatera Province

This section introduces replanting scenarios for targeted districts in North Sumatera Province. Replanting scenarios reflect replanting interventions used in the Indonesian government's programme to rehabilitate low-productive plantations within the supply network, by providing replanting aid for rubber smallholders. This programme faces challenges in determining appropriate allocations for replanting interventions in several districts within Indonesia's natural rubber supply network.

To support the Indonesian government's programme, the approach was subsequently applied in the development of sustainable replanting intervention scenarios for five selected districts, including Langkat, Deli Serdang, Asahan, Simalungun, and South Tapanuli. These districts were selected owing to different trends appearing within the operational validation process (see Section 5.4) that illustrate appropriate conditions for testing the reliability of the strategic planning tool. Around 70% of North Sumatera natural rubber supplies are produced in these districts. Each district has different conditions of rubber plantation, particularly around the configuration of the age of rubber trees.

Replanting intervention scenarios are determined based on discussions with related stakeholders (the North Sumatera Province Plantation Agency and Natural Rubber Primary Processor Association). These stakeholders proposed replanting interventions of 100-1,000 Ha per district for the next five years (2016, 2017, 2018, 2019, 2020). This scenario was selected based on the current allocation of funding from the Indonesian Government for the replanting intervention programme, which covers the cost of replanting up to 1,000 Ha per district. Furthermore, historical data from these districts shows that low-productive areas in Langkat District range between 100-1000 Ha. Table 6.1 shows replanting scenarios for targeted districts.

Table 6.1 Replanting Scenarios for Targeted Districts in North Sumatera Province over the Next Five Years (2016-2020)

Replanting Scenario	**Value (in Hectares)**
1	100
2	200
3	300
4	400
5	500
6	600
7	700
8	800
9	900
10	1,000

6.2 Sustainability Indicators for Formulating Replanting Policies

This section introduces sustainability indicators for formulating replanting policies in North Sumatera's natural rubber industry. These indicators are taken from a list of sustainability indicators in Chapter Five. The indicators were selected based on discussions with an expert panel around the current condition of North Sumatera's natural rubber industry. Six indicators have been selected including:

- Future natural rubber supply and the population of rubber smallholders with immature land for the economic dimension
- Carbon stock levels and CO_2 sequestration levels for the environmental dimension
- Population of rubber smallholders and population of tappers for the social dimension

The future natural rubber supply is an important indicator, because the currently reduced level of rubber supplied in North Sumatera Province has disturbed the stability of other key players, including primary processors. Rubber smallholders with immature land are more susceptible owing to lack of income from rubber plantations at immature phases. The population of rubber smallholders with immature lands is therefore important to maintain. Carbon stock levels and CO_2 sequestration levels also relate to environmental benefits of rubber plantations, both of which influence the quality of air. It is important to manage these environmental indicators in order to maintain the quality of the environment within the supply network. Furthermore, the population of rubber smallholders and tappers reflects the impact of rubber plantations in absorbing people involved in latex production.

Table 6.2 References for Each Indicator in Targeted District

District	Ref for supply (Kg)	Ref for Smallholder Population with Immature Area (People)	Ref for Carbon Stock Level (Ton C)	Ref for CO_2 absorption (Ton CO_2 e)	Ref for Smallholder population (People)	Ref for stepper population (People)
Langkat	30,000,000	2,200	4,000,000	200,000	22,000	45,000
Deli Serdang	6,000,000	600	550,000	70,000	5,500	6,500
Asahan	6,000,000	1,500	550,000	30,000	8,000	6,500
Simalungun	12,500,000	900	1,200,000	65,000	9,500	13,500
South Tapanuli	18,000,000	3,500	1,800,000	100,000	30,000	20,000

After selecting indicators, the target for each indicator needs to be assigned. The target of each indicator reflects the specific level desired by actors within the natural rubber industry. For example, target for the future rubber supply represents the level of supply that is being aimed towards as a future goal. The target for each indicator is used as a reference to convert the assessment results into the index through composite indicators. Furthermore, the target for each indicator is determined through each targeted district. Due to the different conditions in each targeted district, the indicator’s targets for each district vary. The indicator’s targets for each district are defined through discussions with an expert panel who consider the current circumstances of targeted districts. Table 6.2 shows references for each indicator and for each targeted district.

6.3 The Sustainability Impacts of Replanting Scenarios

The purpose of this section is to illustrate the sustainability impacts of replanting scenarios for Langkat District that have been generated through the application of hybrid simulation models. The impacts of replanting are presented in two sections: Section 6.3.1 delivers the impact of replanting on the sustainability of the supply network at district level, and Section 6.3.2 introduces the impact of replanting on the sustainability of the supply network at an individual level.

Simulation experiments were carried out to assess the impact of replanting scenarios on the five selected districts. Since there are ten replanting scenarios (see Table 6.1), the simulation was designed to run 10 times for each district, in order to generate the impact for each replanting scenario. Simulation times for system dynamics were on a yearly basis, while the simulation time for the agent-based simulation was on a daily basis. The simulation was run for 20 years (in model time) for system dynamics, and 20 days (model time) for the agent-based simulation.

Before the simulation experiment was carried out, the design parameters for simulation models were determined. System dynamics and agent-based models consist of several parameters, which can be adjusted based on the target district to be simulated. For example, parameters of production rates for every hectare of plantation can vary for each phase of the life-cycle. Parameters for simulation models were determined from the literature and from discussions with related stakeholders in the expert panel. The complete setting of parameters system dynamics and for agent-based simulation can be observed in Appendix C.

The setting of parameters was followed by the determining of initial data for simulation. Some variables in simulation models require initial data. Immature area, for example, requires initial data as a starting point. Initial data for simulation were collected from North Sumatera Province Plantation Agency and the Indonesia Statistic Agency (BPS). However, not all data are available in government agencies, including data related to total village suppliers and total district suppliers. Data regarding the latter therefore had to be assumed. In Table 6.3, data from selected districts are summarized.

Table 6.3 Initial Data for Implementation of Simulation Model

District	**Composition of Plantation Area**			**Distribution of Supplier**		
	Immature Area (ha)	**Productive Area (ha)**	**Unproductive Area (ha)**	**Rubber Smallholders (People)**	**Village Suppliers (People)**	**District Suppliers (People)**
Langkat	3,812	39,860	4	22,469	225	22
Deli Serdang	1,347	4,527	446	4,816	48	6
Asahan	569	6,348	346	8,807	88	10
Simalungun	1,661	12,462	134	9,152	92	4
South Tapanuli	5,942	9,875	8,526	28,147	281	24

6.3.1 The Impact of Replanting Scenarios on the Sustainability of the Supply Network at District Level

This section presents the impact of replanting scenarios on the district level sustainability of the Langkat upstream natural rubber supply network. These impacts were gauged from the application of the system dynamics model. The impacts of replanting scenarios are presented for each key performance indicator and are delivered in four sub-sections, including the impacts of replanting scenarios in rubber plantation areas, the impacts of replanting scenarios in the economic dimension, the impacts of replanting scenarios in the environmental dimension, and impacts of replanting scenarios in the social dimension. In the sub-section related to the dynamic change of rubber plantation land, resulted are presented for three indicators, including productive area, immature area, and the old plantation area. As regards the economic dimension, results are presented for three indicators, including latex production, utilization of the primary processor, and population of smallholders with immature land. For the environmental dimension, results are presented for four indicators, including emissions from fertilizer, emissions from replanting, carbon stock levels, and carbon sequestration levels. For the social dimension, results are presented for four indicators, including the population of smallholders, the population of tappers, the population of village suppliers, and the population of district suppliers.

6.3.1.1 Impact of Replanting Scenarios on Rubber Plantation Areas

This section presents the impact of replanting scenarios on rubber plantation areas in Langkat district. One main ability of the system dynamics model is in the representation of dynamic change in rubber plantation areas. This change is caused by the configuration of dynamics around shifting rubber tree ages within the network. Replanting comprises one variable that can modify the composition of rubber plantations. Replanting transforms low-productive areas into immature areas.

Figure 6.3 gives an estimation of future productive areas with replanting scenarios from the government. It can be seen that in the next 10 years, productive areas will decrease significantly, from around 40,000 hectares to around 17,000 hectares in 2025. This reduction will continue after 10 years, if replanting scenarios are not applied. It can be observed that total productive areas with no replanting scenarios will continue to decline to around 15,000 hectares in the next 20 years. Simulation results show that replanting scenarios are likely to increase the total productive area, if implementation could begin in the next 10 years.

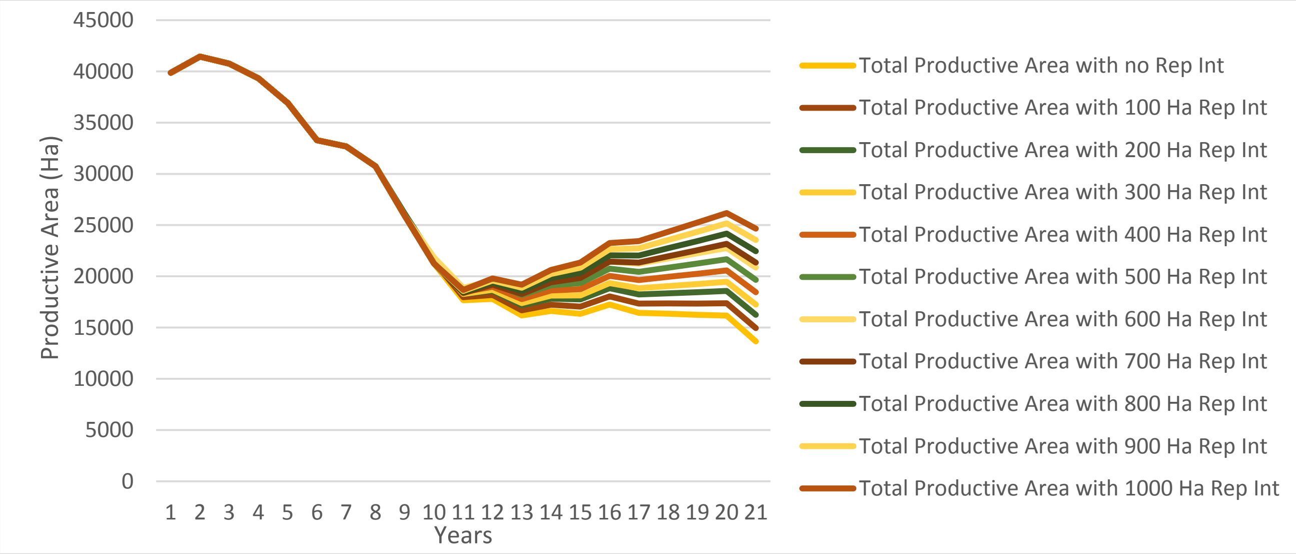


Figure 6.3 The Impact of Replanting Scenarios on Productive Area in Langkat

The implementation of a 1,000 Hectare replanting scenario is likely to produce the highest productive area, with more than 25,000 Hectares over the next 20 years. This is followed by a replanting scenario of 500-900 Hectares per year. Replanting scenarios at this rate would maintain productive areas at between 20,000-25,000 Hectares over the next 12 years. Replanting scenarios below 500 Hectares per year are expected to produce productive areas of less than 20,000 Hectares in next 12 years. Although the implementation of a 1,000 Hectare replanting scenario per year is likely to keep future productive areas at around 20,000 Hectares, this implementation will increase the total of immature areas in the next 10 years. Figure 6.4 shows the projected dynamic change of immature areas for Langkat District over the next 20 years.

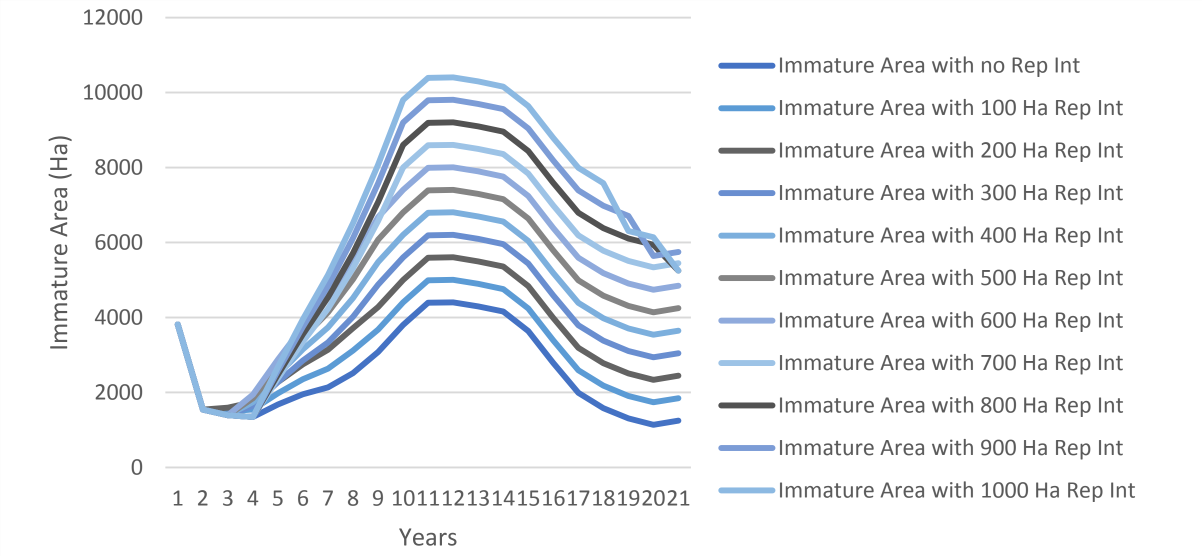


Figure 6.4 The Impact of Replanting Scenarios on Immature Areas in Langkat

It can be seen from Figure 6.4 that total amount of immature areas in Langkat district will increase significantly with increases in total replanting areas. The simulation model predicts that the total immature area would come to around 4,000 Hectares in the next 10 years if replanting scenarios were not applied to the district. The total immature area is likely to increase in the next 10 years owing to the fact that many productive areas are expected to enter a low-productive phase within this time. The implementation of replanting scenarios would have a greater impact through increasing immature areas to 4,000 Hectares or higher.

The implementation of a 1,000 Hectares replanting scenario is likely to have the highest impact in immature areas. It is expected that this scenario will increase the total immature area to around 10,000 Hectares in the next 10 years. Replanting scenarios with less than 500 Hectares per year are expected to increase immature areas to less than 7,000 Hectares in the next 10 years. However, the increase in immature areas is likely to change after 10 years. This could be caused by reductions in the total of low-productive plantation areas after 10 years.

Another important issue related to rubber plantation areas is the total amount of old plantations within the network. Old plantations are rubber plantations that have entered a low-productive phase, but whose owners have decided to retain old rubber trees. This type of plantation has a low productivity level. Simulation results show that the total number of old plantations in Langkat district is likely to increase in the next 10 years. This is owing to the total of low productive areas being greater than the total replanting rate and related replanting scenarios. Figure 6.5 shows that the total number of old plantations is expected to occupy around 8,000 Hectares in the next 10 years, if replanting scenarios are not applied to Langkat district. Replanting scenarios are likely to reduce the total number of old plantations in Langkat. The implementation of a 1,000 Hectares replanting scenario is likely to reduce the total number of old plantations to around 6,000 Hectares in the next 10 years. The high rate of old plantations within the supply network can reduce latex production and reduce the income of rubber smallholders, owing to the low productivity of old plantations.

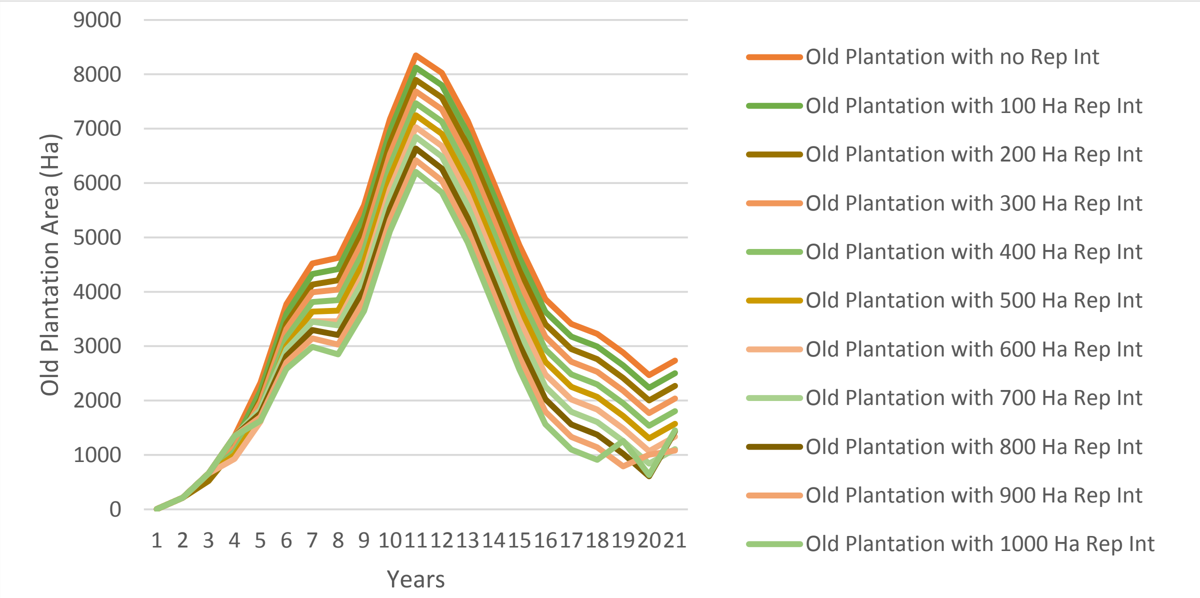


Figure 6.5 The Impact of Replanting Scenarios on Old Plantation Areas in Langkat

6.3.1.2 The Impact of Replanting Scenarios on Economic Dimensions

This section illuminates the impacts of replanting scenarios on economic dimensions. Replanting scenarios were found to have a significant impact on the economic situation of the supply network. The main impact of replanting scenarios can be observed in the fluctuation of latex production within the network. As replanting converts low-productive areas into immature areas, replanting influences future latex production. Replanting is a key component in sustaining natural rubber supply as it introduces a new life-cycle of rubber plantation. As a result, the future natural rubber supply is mainly dependent on replanting activity, particularly if there is no available land for opening a new plantation.

Figure 6.6 illustrates the trend of latex production in Langkat district over the next 20 years. As is seen, the simulation models predict a declining trend in latex production over the next 10 years. This is mainly brought about by reductions to productive areas in the next 10 years. However, the implementation of replanting scenarios is likely to alter the decreasing trend in latex production. Replanting scenarios are likely to increase latex production after 10 years. This upward trend is caused by results from replanting scenarios in immature areas, as the latter start to become productive after 10 years, given that rubber trees need 6 years to become productive. It can furthermore be seen in Figure 6.6 that the implementation of 600-1,000 Hectares replanting scenarios is likely to keep latex production higher than 20,000 tons per year, while without replanting scenarios, latex productions will continue to decline to less than 15,000 ton per year over the next 20 years.

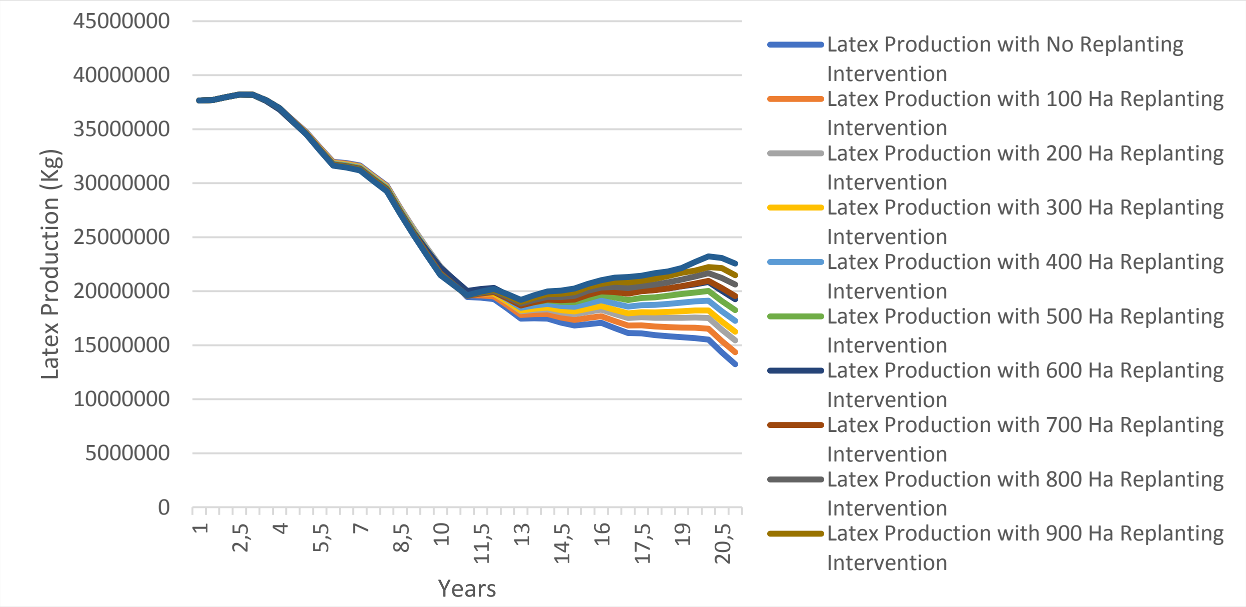


Figure 6.6 The Impact of Replanting Scenarios on Latex Production in Langkat

The reduction of latex production has multiple impacts on other key players in the supply network. The primary processor comprises one player impacted by reductions in latex production. As has occurred in North Sumatera Province, primary processors reduced factory utilization owing to dwindling supplies from rubber plantation in the province. One of the economic indicators in the simulation models relates to the utilization of primary processors. This indicator is used for comparisons between the total capacities of primary processors within the network and total latex production in the network.

Figure 6.7 shows how the utilization of primary processors is likely to reduce in the next 10 years owing to diminished latex production, from around 0.09 to around 0.05. Replanting scenarios can nevertheless enhance the utilization of primary processors. The implementation of 600-1,000 Ha replanting scenarios could keep utilization higher than 0.05. The utilization of primary processors would, however, remain diminished without replanting scenarios. The value of utilizations is calculated by comparing 400,000 tons (the total capacity of primary processors in North Sumatera Province) with the latex production from Langkat district.

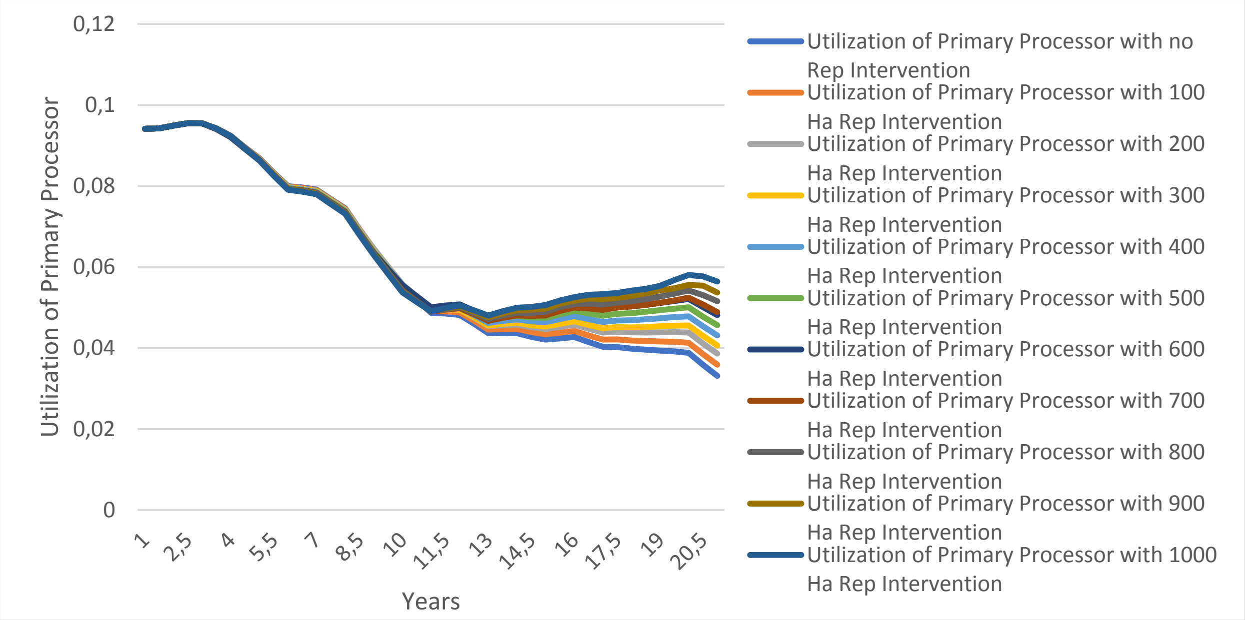


Figure 6.7 Impact of Replanting scenarios on Utilization of Primary Processor in Langkat

Another important issue related to economic dimensions is the population of rubber smallholders with immature land. As discussed previously, rubber plantations at immature phases will not produce latex. As a result, rubber smallholders forfeit their income from latex. This situation puts rubber smallholders in difficult situations, particularly when their livelihoods mainly depend on income from rubber plantations. Moreover, high populations of rubber smallholders with immature land will reduce the purchasing power within the network. As a result, this situation can influence the economic growth of those areas.

Figure 6.8 illustrates how the population of rubber smallholders with immature areas is likely to increase in the next 10 years following the increase in total immature areas. The implementation of replanting scenarios contributes to increases in the population of rubber smallholders with immature areas. It is expected that the population will reach around 4,000 people with the implementation of a 1,000 Ha replanting scenario in the next 10 years. The implementation of 500-900 Hectare replanting scenarios per year over the next 10 years would double the population of rubber smallholders with immature land at the end of year 11. However, following this, the population will start to decline owing to the fact that many immature areas will enter the productive phase. Such considerations have been recommended to the government in planning for replanting scenarios. Different alternatives regarding income should also be considered, such as intercropping systems and livestock systems at immature phases. Furthermore, the replanting aid provided by the government should cover the life costs of rubber smallholders for several years during immature phases.

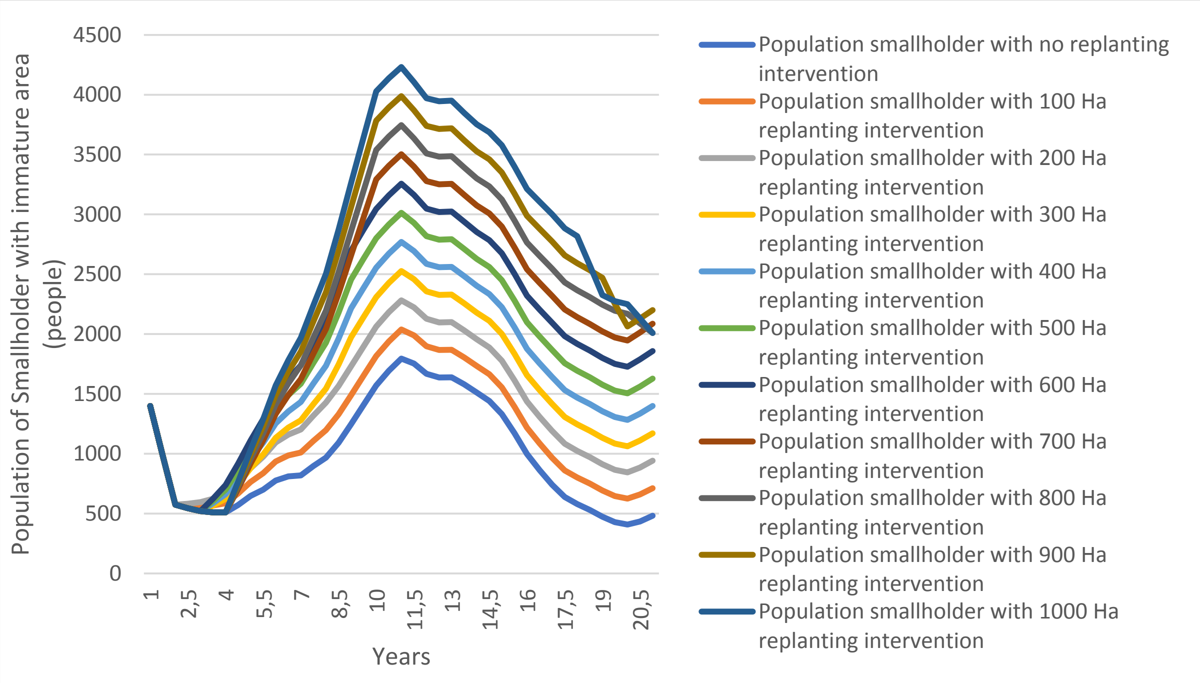


Figure 6.8 The Impact of Replanting Scenarios on the Population of Smallholders with Immature Areas in Langkat

6.3.1.3 Impact of Replanting Scenarios on Environmental Dimensions

This section introduces the impact of replanting scenarios on environmental dimensions in Langkat district. The production of latex not only has economic benefits within the network, but also influences the environmental balance. Although the production of latex has a positive impact on environment through absorbing carbon and through stocking carbon, the negative impacts of emissions from fertilizer implementation and replanting activities are unavoidable. This section elaborates on the dynamics of environmental impacts caused by the application of replanting scenarios in the supply network.

The first discussion in this section relates to fertilizer use among rubber smallholders. Petsri et al (2013) have argued that fertilizer is a fundamental source of emissions in rubber plantation. Emissions from fertilizers mainly depend on the total amount of fertilizer implemented by rubber smallholders. Although standard uses of fertilizer for rubber plantations have been constructed and recommended by researchers (Petsri et al., 2013), based on the interview results given in the case study chapter, the implementation of fertilizer by rubber smallholders was influenced by factors including latex price, fertilizer price, the availability of fertilizer, and the impact of fertilizers. These factors were subsequently analysed in order to produce a utility model for the modelling decisions of smallholders (see Section 4.2.1). Using the utility function in Section 4.2, the implementation of fertilizers by smallholders in Langkat district was predicted.

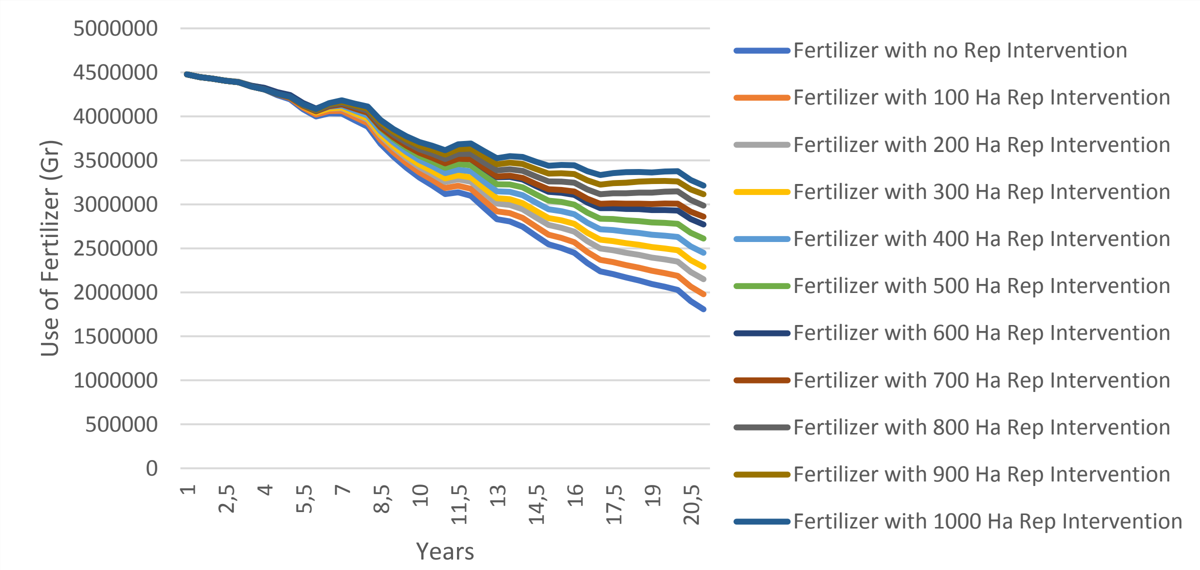


Figure 6.9 Impact of Replanting Scenarios on the Use of Fertilizer

Figure 6.9 illustrates fertilizer use in Langkat district. Simulation models predict a decreasing trend in fertilizer use over the next 20 years. Declines in productive areas contribute to this reduction in fertilizer use. Rubber plantations require various amounts of fertilizer for each phase in a rubber plantation's life cycle. For example, productive areas require more fertilizer compared to immature areas (Petsri et al., 2013). The reduction of productive areas will therefore diminish fertilizer use within the network. Another factor relates to utility function in predicting the low probability of rubber smallholders applying fertilizer to their land. This is because influential factors in the simulation were set at their lowest level according to the real conditions of North Sumatera Province. It can be observed, furthermore, in Figure 6.9, that replanting scenarios influence fertilizer use. A 1,000 Ha replanting scenario was found to have the biggest impact on fertilizer use. At this rate of replanting scenario, fertilizer use in Langkat district is expected to be around 3,500 kg in the next 20 years. Contrastingly, the level of fertilizer use will continue to decrease to around 2,500 kg in the next 20 years if replanting scenarios are not applied to the Langkat district.

Based on the uses of fertilizer, fertilizer emissions are calculated. The dynamics of emissions from fertilizer follow trends in fertilizer use. Figure 6.10 show that emissions from fertilizers in Langkat district are expected to be around 15,000-25,000 t CO2 e over the next 20 years, for different replanting scenarios. The lowest emissions are found when there is no replanting scenario applied within the network. The implementation of replanting scenarios can therefore enhance emissions from fertilizers. Replanting scenarios with a rate of between 600-1,000 Ha per year are likely to increase emissions from fertilizers by 75%, compared with emissions from fertilizers without replanting scenarios.

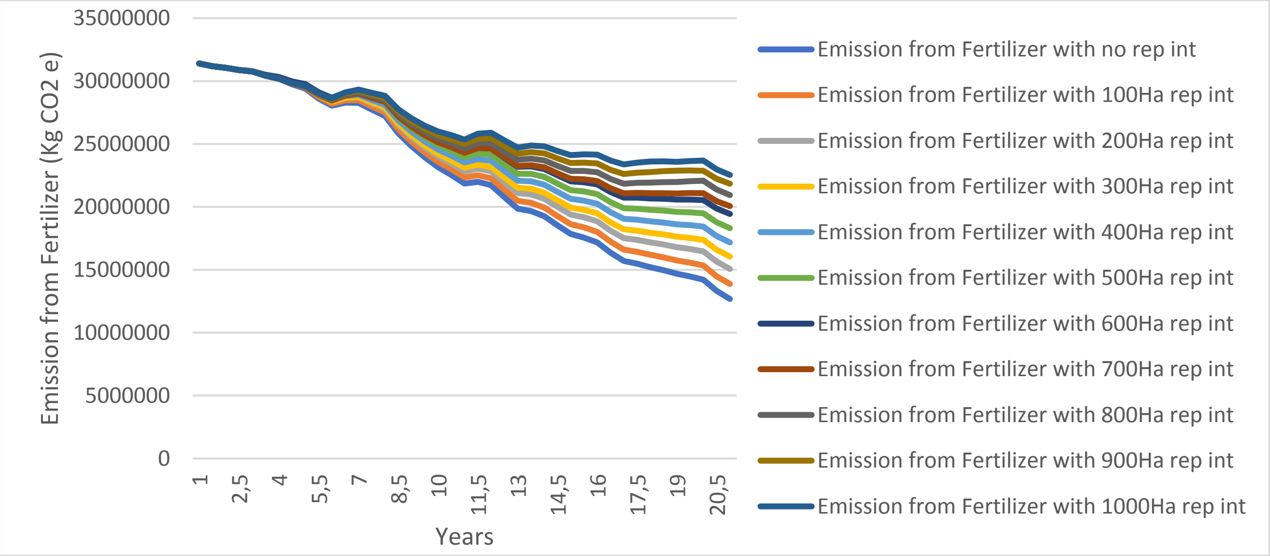


Figure 6.10 Impact of Replanting Scenarios on Emissions from Fertilizer

Another source of emission is found in replanting activities. The latter emits CH_4 and N_2O from burning the biomass of old rubber trees (Petsri et al., 2013). Rubber smallholders carry out burning processes to remove the residue from old rubber trees. The burning process is an effective and cheap process for clearing the land, but the process makes unnecessary emissions in the environment. The simulation models predict the rate of CH_4 and N_2O emissions in Langkat district for the next 20 years.

Figure 6.11 and 6.12 illustrate the total CH_4 and N_2O emissions for the next 20 years. It is expected that, without replanting scenarios, the network will produce CH_4 emissions at around 20 t CH_4 e. This emission is likely to increase in year 10 to 12 to more than 40 t CH_4 e. This is owing to the fact that many productive areas are expected to enter a low productive phase at this time. However, the implementation of replanting scenarios will increase CH_4 emission significantly. The implementation of a 1,000 Hectare replanting scenario will increase CH_4 to more than 200% compared with emission levels without a replanting scenario. A similar trend can be found for N_2O. It is expected that N_2O emissions will be around 0.5 t N_2O e for the next 20 years, without a replanting scenario. The implementation of a replanting scenario will increase total N_2O emission. The implementation of a 1,000 Ha/year scenario is found to have the highest N_2O emission within the network. The implementation of replanting scenarios should thus consider this fact owing to the adverse impact on quality of air, particularly while replanting scenarios are concentrated in certain locations. For example, when 1,000 Ha replanting is focused in one sub-district at the same time, this causes a large emission in that area, since rubber smallholders tend to perform burning processes at the same time.

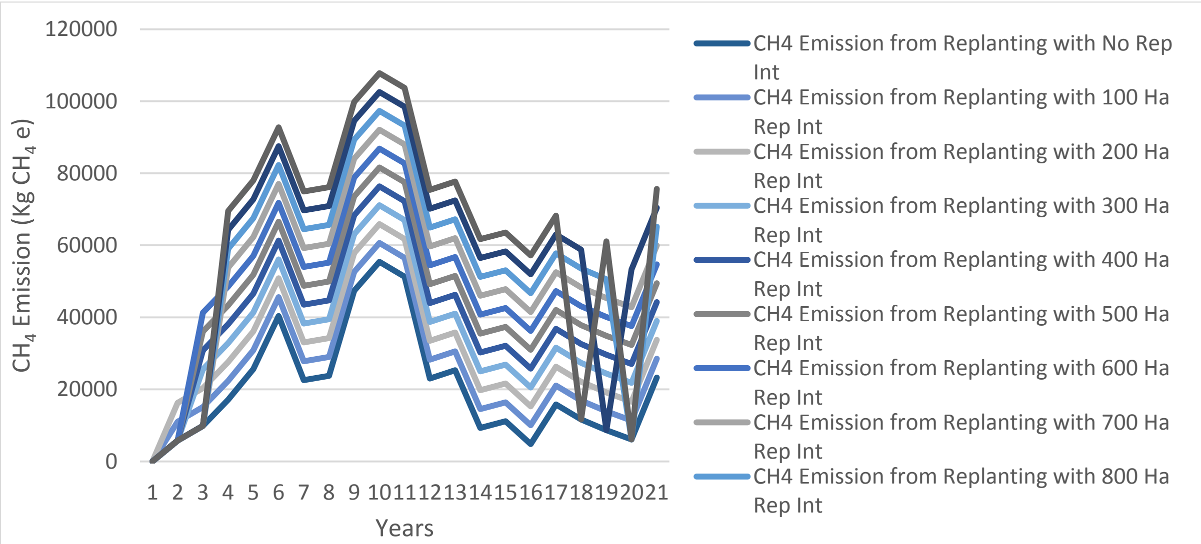


Figure 6.11 Impact of Replanting Scenarios on CH_4 Emissions

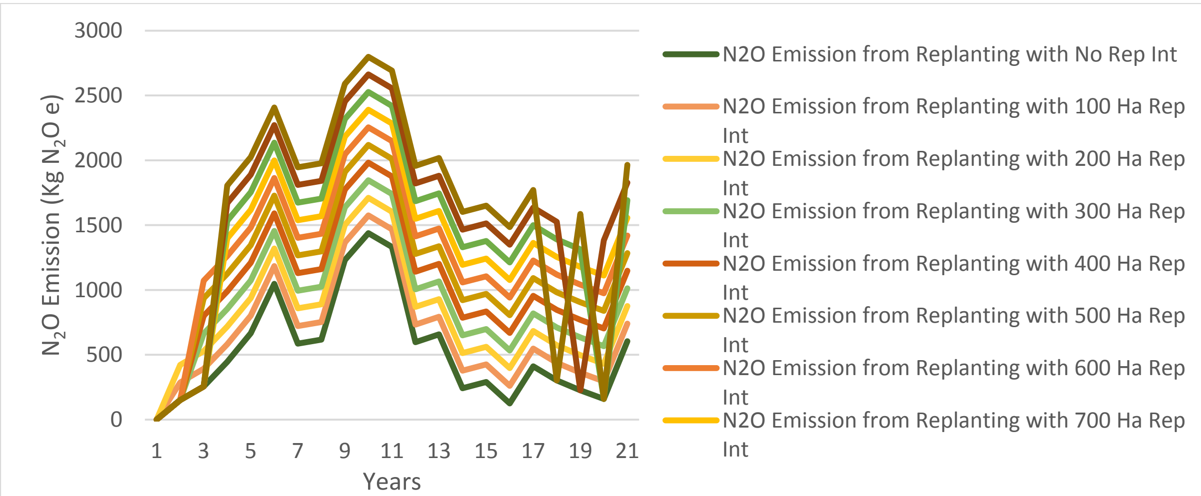


Figure 6.12 Impact of Replanting Scenarios on N_2O Emissions

Rubber plantations do not bring only negative impacts to the environment. They also have positive impacts, such as their ability to absorb CO_2 and to stock carbon within trees, both of which are important in improving the quality of the environment. Rubber trees absorb carbon dioxide and convert it into both oxygen (O_2) and carbon. Carbon is stored inside the tree, above the ground, below the ground, and in harvested latex. The abilities of rubber plantations to act as a form of carbon storage change dynamically throughout natural rubber's life cycle (Petsri et al., 2013). Rubber plantations at the productive phase have a higher ability to store carbon compared with rubber plantations at an immature phase. As a result, replanting activities influence carbon stock levels within the network, since this activity contributes to increases in immature areas. Simulation models can predict the dynamics of carbon stock levels in the network according to the life-cycle of rubber plants.

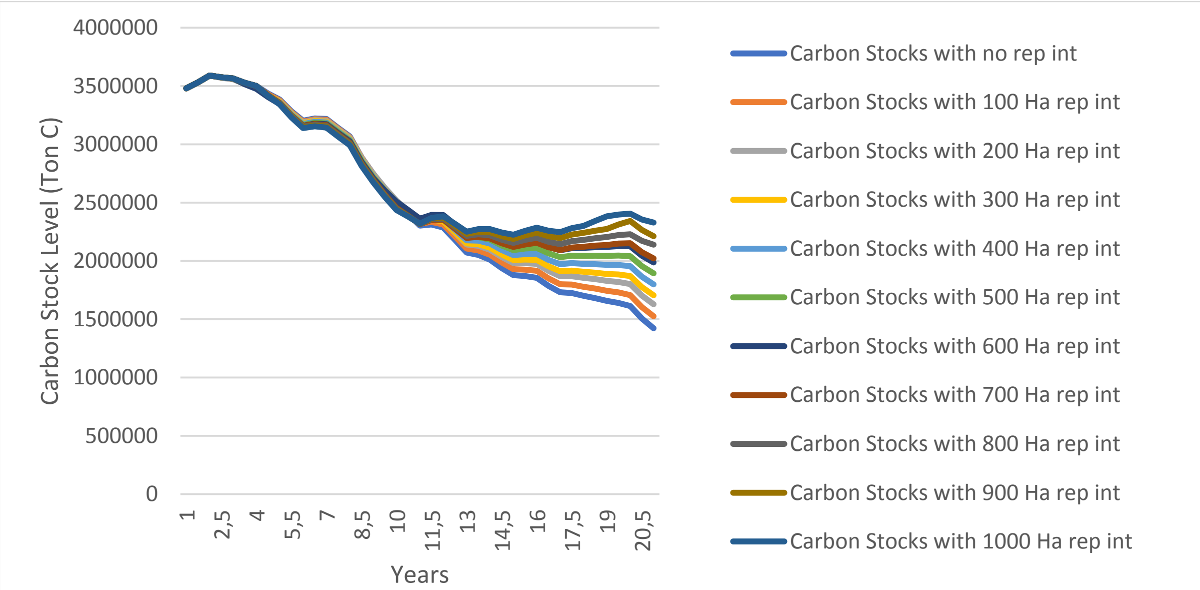


Figure 6.13 Impact of Replanting Scenarios of Carbon Stock Levels

Figure 6.13 illustrates the dynamics of carbon stock levels in Langkat district. The carbon stock levels in Langkat district is likely to decline in the next 20 years. Carbon stock levels will fall from 3,500 M t C to around 1,500 M t C in the next 20 years if replanting scenarios are not applied. Replanting scenarios will reduce current carbon stock levels because the activity converts old plantation areas with a high ability to store carbon into immature areas, which have low carbon storage abilities. As a result, the benefit of replanting activities can be observed in the results of replanted immature areas entering productive phases. This can be seen in Figure 6.13: carbon stock levels will start to increase after year 11, while immature areas resulting from replanting activities enter a productive phase within year 1-10. A 1,000 Hectare replanting scenario is found to produce the highest carbon stock levels after year 11. However, this intervention will reduce carbon stock levels, as shown in projected data for the next 10 years.

Another positive impact of rubber plantations is in their ability to absorb carbon dioxide. This contributes to improving the quality of air within the network. Rubber plantations with productive areas are crucial for absorbing carbon dioxide. Simulation models can predict the carbon dioxide sequestration level from rubber plantations within the network. Figure 6.14 illustrates the total level of carbon dioxide sequestration in the Langkat district.

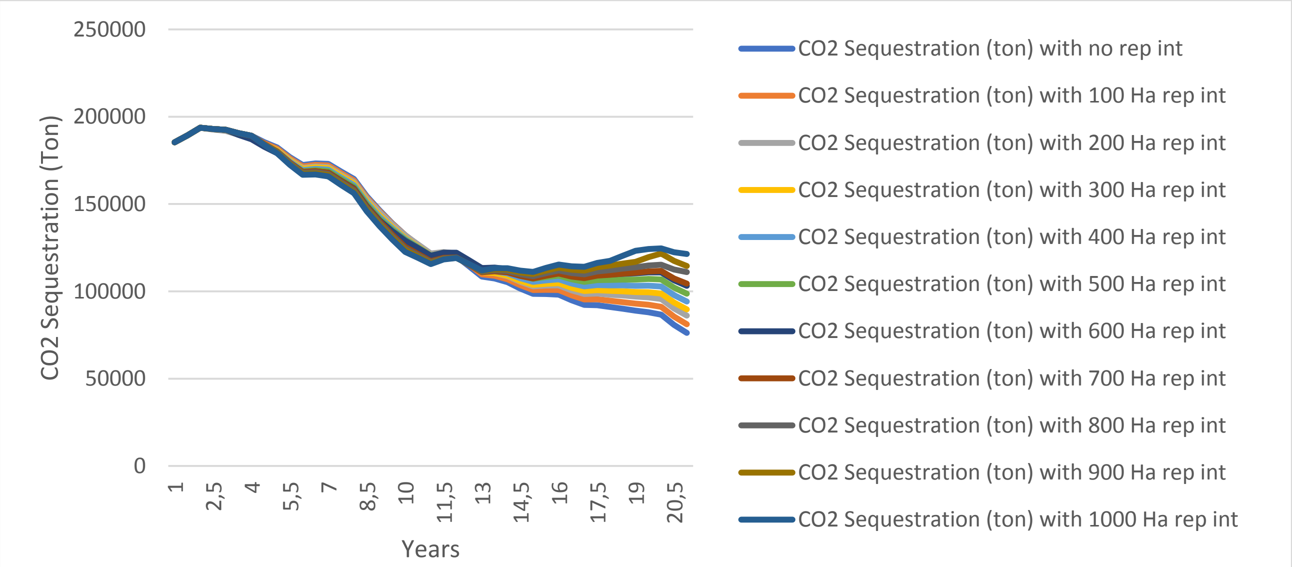


Figure 6.14 Impact of Replanting Scenarios on CO_2 Sequestration Level

It can be seen from Figure 6.14 that carbon dioxide absorption is likely to diminish in the next 20 years. Currently, rubber plantations in Langkat district can absorb around 200,000 tonnes of carbon dioxide per year. However, this would decline in concomitance with reductions to productive areas in the Langkat district. Replanting contributes to reductions in carbon dioxide sequestration levels by converting old plantations into immature areas, which are not very well able to absorb carbon dioxide. However, replanting would enhance future carbon dioxide sequestration level after replanted immature areas have entered productive phases, at which point they will have the complete ability to absorb carbon dioxide.

This trend can be observed in Figure 6.14. Replanting scenarios are likely to diminish carbon dioxide sequestration levels between year 1 to year 10. The benefits of replanting scenarios can be observed after year 12, when immature areas enter the productive phase. It is expected that a 1,000 Ha replanting scenario per year will keep carbon dioxide sequestration levels at around 120,000 tonnes after year 12, while without replanting scenarios, carbon dioxide sequestration levels will continue to fall below 100,000 tons per year.

6.3.1.4 Impact of Replanting Scenarios on Social Dimensions

This section introduces the impact of replanting scenarios on the social dimensions in Langkat district. Rubber plantations become a source of income to the social community within the supply network. Many people within the network can be involved in latex production and its distribution process. Professions including tappers, village suppliers, and district suppliers are all required within the network, and people who live near rubber plantations are often selected to organise these professions. As a result, rubber plantations can enhance the welfare of people within the network.

However, the stability of these professions is mainly dependent on the availability of productive areas within the network. For example, tapping is only required while plantations are at a productive phase, so that latex can be tapped from rubber trees. While plantations are at an immature phase, tapping is not required, since rubber trees are not able to produce latex. This shows that the social impact of rubber plantations can change dynamically according to the life cycle of rubber plantations. This section illustrates the dynamic change in social sustainability of rubber plantations in Langkat district.

Rubber smallholder comprises the main profession in the natural rubber supply network. Majority of rubber smallholders receives their income from the rubber plantation. The population of rubber smallholders in the network can change dynamically over time. The population of rubber smallholders can increase owing to the opening of new rubber plantations, but this population can also decrease when rubber smallholders convert to other crops. Figure 6.15 shows the dynamics of the rubber smallholder population in Langkat district.

Simulation models predict reductions in the rubber smallholder population in Langkat for the next 20 years. Currently, the population of smallholders in Langkat is at around 16,000 people. This population is expected to reduce to around 6,500 people in the next 20 years if replanting scenarios are not implemented. This reduction is caused by the likelihood of many rubber smallholders with old plantations converting to other crops. The implementation of replanting scenarios is likely to stop this reduction in the population. Furthermore, replanting scenarios will reduce the rate of crop conversion. Figure 6.15 shows that the implementation of 1,000 Ha replanting scenarios per year would keep the population of rubber smallholders at more than 12,000 people in the next 20 years. Replanting scenarios with a rate of less than 500

Ha per year would keep the population of smallholders between 8,000 – 10,000 people at the end of year 20. Reductions to the rubber smallholder population can trigger multiple impacts that reduce the population of other players within the network.

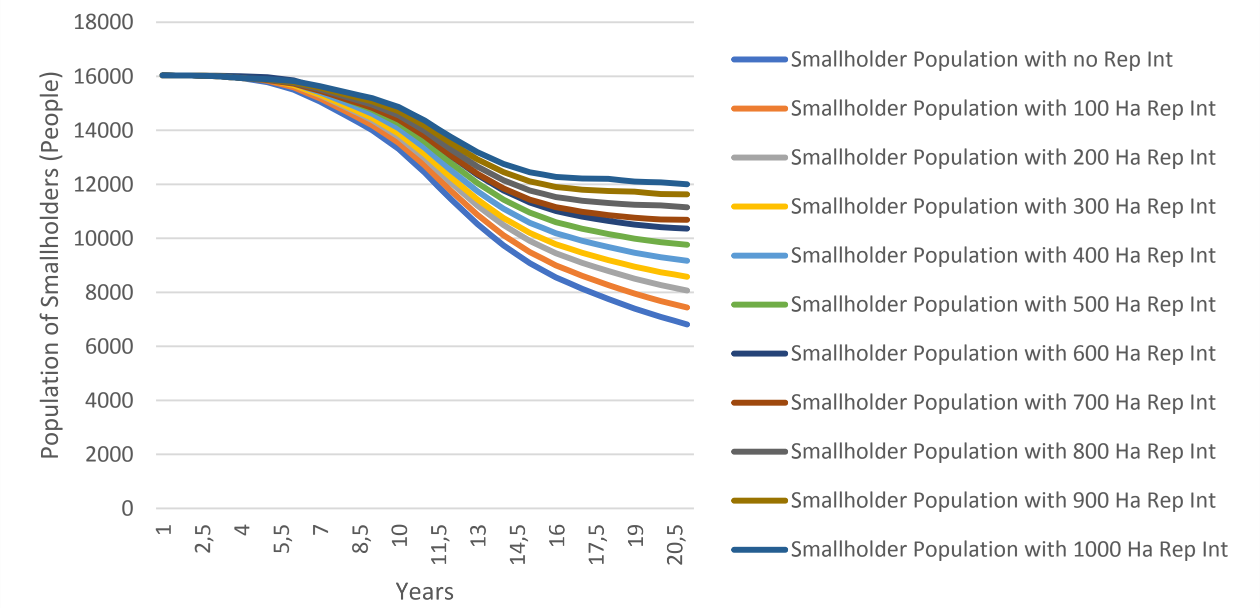


Figure 6.15 Impact of Replanting Scenarios on the Population of Rubber Smallholders

The next profession that will be impacted by the life cycle of rubber plantations is tapping. This profession involves tapping rubber trees in order to produce latex. In reality, many rubber smallholders hire someone else to tap their plantations. People who live near plantations are usually selected as tappers. For these people, the profession is used as an additional source of income. However, the demand for tappers is mainly influenced by the range of total productive areas. Since the total productive area changes dynamically over time, the population of tappers also changes.

Figure 6.16 shows the fluctuations in tapper population in Langkat. It is expected that the tapper population will decline over the next 20 years. Although there is a slight projected increase in population in the next 4 years, the reduction of the tapper population is expected to fall from around 40,000 people to around 18,000 people in the next 20 years, if replanting scenarios are not applied to the network. The implementation of replanting scenarios is likely to reduce the current population of tappers, but it is conversely likely to boost tapper population in the future. Figure 6.16 shows how the implementation of 1,000 Ha replanting scenarios would reduce the current tapper population. This can be observed from year 1 to year 10, when the population of tappers with 1,000 Ha replanting scenarios is below the population of tappers with no replanting scenarios. However, this trend is likely to change after year 12, when the population of tappers with 1,000 Ha replanting scenarios is higher than the population of tappers with no replanting scenarios. This is owing to replanted immature areas in year 1 to year 10 entering the productive phase.

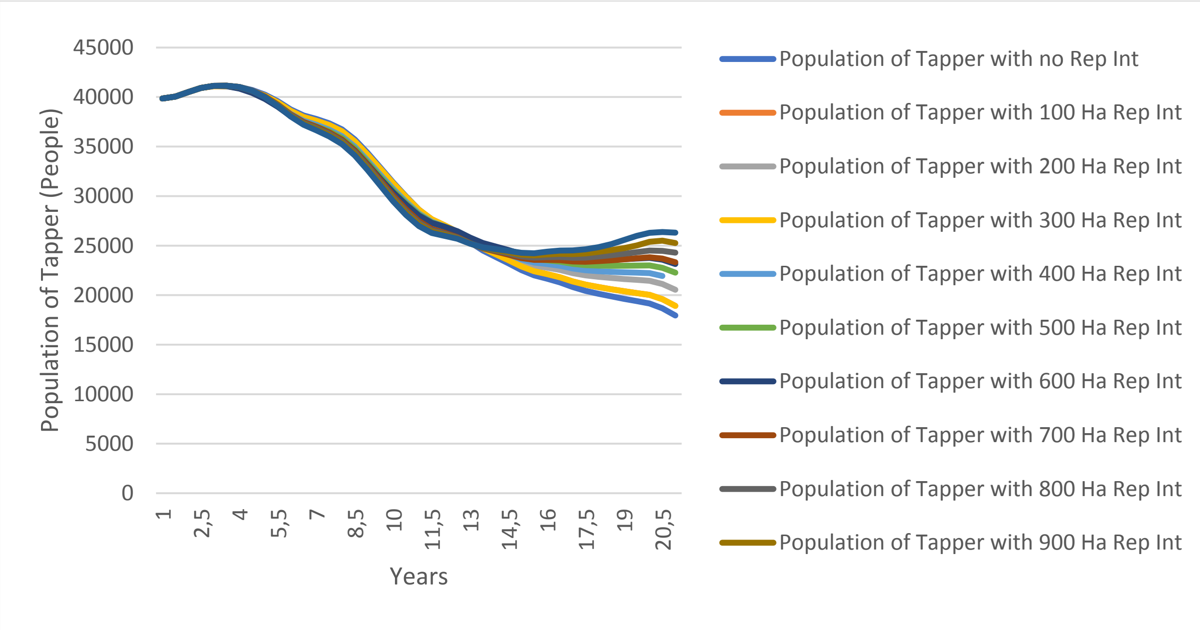


Figure 6.16 Impact of Replanting Scenarios on Population of Tapper

Other players impacted by the dynamic change in rubber plantations are latex suppliers. The dynamic change in rubber plantation resulting from the life cycle of plantations causes fluctuations in latex production, which in turn affect the population of latex suppliers. The reduction of latex production will decline the total of latex that will be generated by latex supplier. If this reduction continues to occur, it will affect the population of suppliers. This situation has occurred in North Sumatera Province. The simulation model predicts the impact of replanting scenarios on the population of suppliers in Langkat.

Figure 6.17 shows that the population of village suppliers is likely to reduce in the next 20 years, concomitant reductions in latex production. Currently, it is expected that total village suppliers in Langkat district numbers around 700 people. This population is expected to fall to around 300 people in the next 20 years, if replanting scenarios are not applied to the network. The implementation of replanting scenarios will enhance the population of village suppliers by maintaining future latex production. It can be seen that 1,000 Ha replanting scenarios per year would keep the population of village suppliers to 400 people. Furthermore, replanting scenarios will reduce the current supply, which can affect the population of village suppliers. Figure 6.17 shows that there are slight differences at year 1 – year 10 between the population of village supplier with no replanting scenarios and the population of village suppliers with 1,000 Ha replanting scenarios.

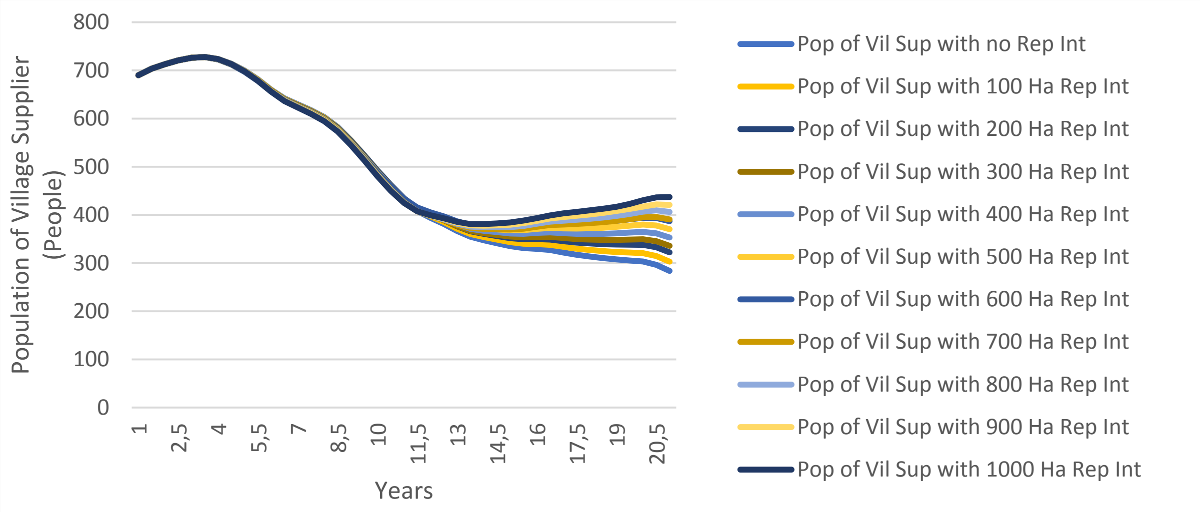


Figure 6.17 Impact of Replanting Scenarios on the Population of Village Suppliers

A similar trend can be observed in the population of district suppliers. This supplier collects latex from village suppliers. The reduction in the village supplier population will reduce the total amount of latex supplied by district suppliers. Figure 6.18 shows how the population of district suppliers is affected by reduced latex production. The current population of district suppliers in Langkat is estimated at around 77 people. This population will likely reduce to around 30 people in the next 20 years if replanting scenarios are not implemented. As shown in Figure 6.18, replanting scenarios are likely to enhance the population of district suppliers in the future. It can also be seen that the population of district suppliers is likely to increase after year 12. This is owing to improvements in latex production that are likely to occur following increases to productive areas.

It can be seen, overall, that replanting scenarios influence the population of key players within the network. This situation relates, in turn, to the welfare of the community within the network. It can furthermore affect the employment rate in a given district. Reductions in the population of key players forces people to find other jobs as an alternative source of income, since old professions are no longer profitable. As a result, the planning of replanting scenarios must be considered for their social impact, in order to ensure the stability of the supply network.

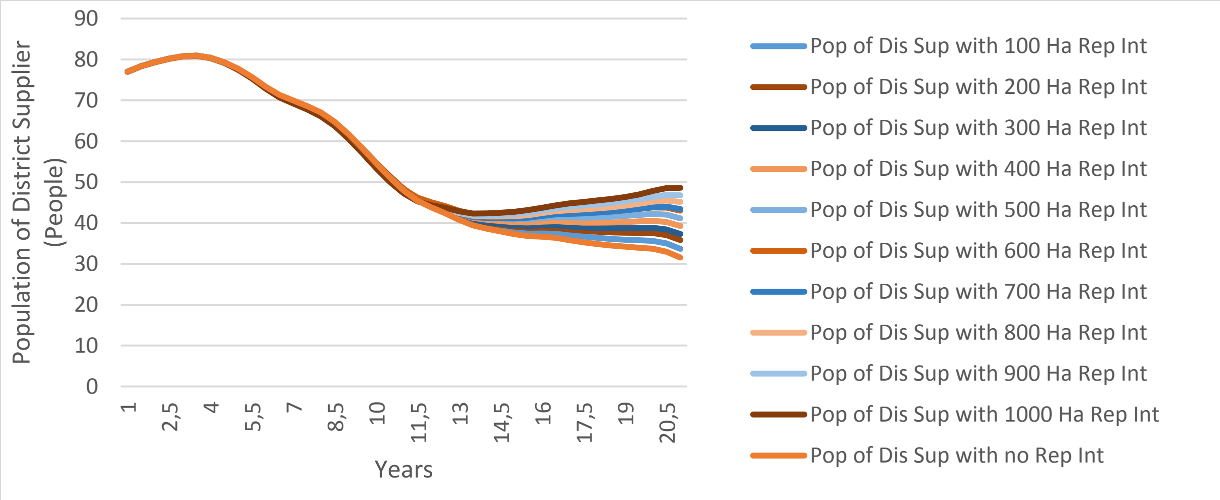


Figure 6.18 Impact of Replanting Scenarios on Populations of District Supplier

6.3.2 The Impact of Replanting Scenarios on the Sustainability of the Supply Network at an Individual Level

This section illustrates the impact of replanting scenarios on key players' performance, on the basis of the application of an agent-based model. While the system dynamics model presents yearly, aggregate data at the district level, agent-based simulation models generate daily, individual data for each player within the network. The impacts of replanting scenarios are presented in three sections including: latex stock data for each key players and the average stock level, average income, and the average distance travelled by suppliers.

6.3.2.1 Impact of Replanting Scenarios on the Average Stock Level of Key Players

This section describes the stock levels of key players and the impacts of replanting scenarios on the average stock level of key players. Stock data incorporate the total amount of latex accumulated by each key player within the network. The fluctuation of stock data reflects the flow of materials between key players. For example, fluctuations in stock for rubber smallholders reflect the flow of latex to village suppliers. Figure 6.19 shows the daily stock level for three village suppliers. 215 village suppliers were scattered in 23 sub districts within the Langkat natural rubber supply network. Agent-based simulation recorded the stock level for each village supplier over 20 days. Each village supplier had a different capacity in buying and stocking latex. This reflected real conditions in the supply network, whereby every village supplier has a different ability regarding the purchasing of latex from rubber plantations. It can be seen from Figure 6.19 that V4 succeeded in reaching 1.200 kg latex in 5 days (one week), while V2 achieved a comparable amount of latex in 11 days. V4 would flow its stock to the district supplier after five days. It can be seen that the reduction of stock levels for V2 and V12 in day 12 indicated that on this day, V2 and V12 flowed their latex stock to district suppliers. V4 succeeded in flowing their stock to district suppliers in 4-5 days, which can be seen in the reduction of stock in V4 occurring in day 6, day 9, day 11 and day 14. This indicates that V4 was likely to gain more income, since the flow of latex was greater than V2 and V12.

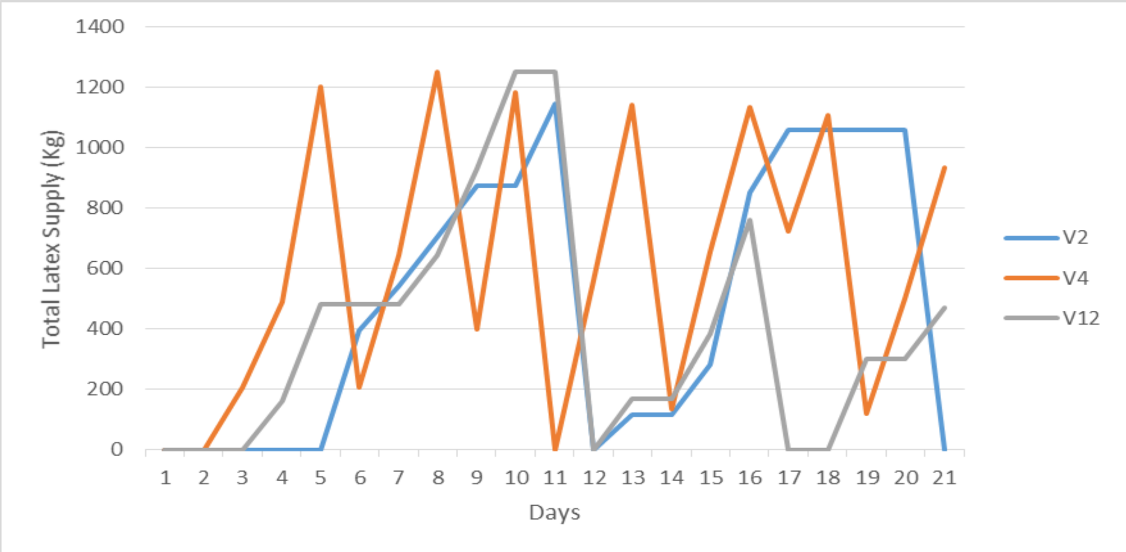


Figure 6.19 Stock Levels for Village Suppliers

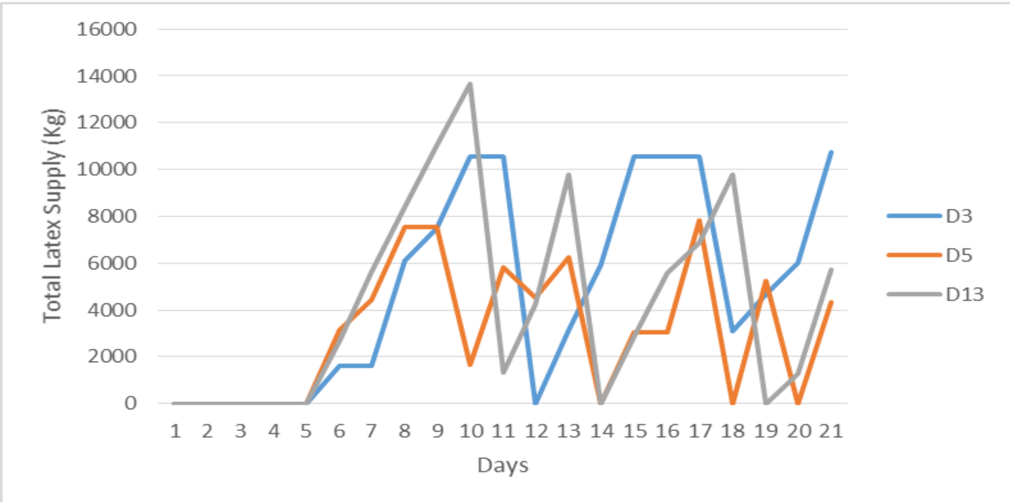


Figure 6.20 Stock Levels for District Suppliers

Figure 6.20 shows the stock levels for district suppliers. Currently, in North Sumatera, district suppliers flow 8-12 tons of latex per week. A similar situation is reflected in the simulation model. Some district suppliers in the simulation model, such as D3 and D13, accumulated 10 tons of latex in 10 days, while other suppliers, such as D5, accumulated around 8 tons of latex over 7 days. The different accumulation times between district suppliers are caused by village suppliers, who send latex at different times. The fluctuations of stock illustrate the flow of latex from district suppliers to rubber traders at primary processors. It can be seen that D3 and D13 sent latex to rubber traders in day 11 and 12, while D5 sent latex on day 10. Every district supplier sends different amounts of latex depending on their accumulation of the material.

This section illustrates the average stock of all key players within the network. This variable can be implemented to investigate the impact of replanting scenarios on the current flow of latex. In the simulation, replanting scenarios were applied to the sub-district, with the biggest population of rubber smallholders residing in Langkat. Since rubber plantations with immature areas will not produce latex, the implementation of the intervention was applied by reducing the population of smallholders in the selected sub-district.

Figure 6.21 shows the impact of replanting scenarios on the average stock of village suppliers. It can be seen that there were slight differences between the average stock with no replanting scenarios, and the average stock with 1000 Ha replanting scenarios. This shows that replanting scenarios with a rate of 100-1,000 Ha is likely to have a minimal impact on village suppliers. This is owing to the substantial population of rubber smallholders in the sub-district. However, increases in the rate of replanting scenarios will likely increase the impact to village suppliers.

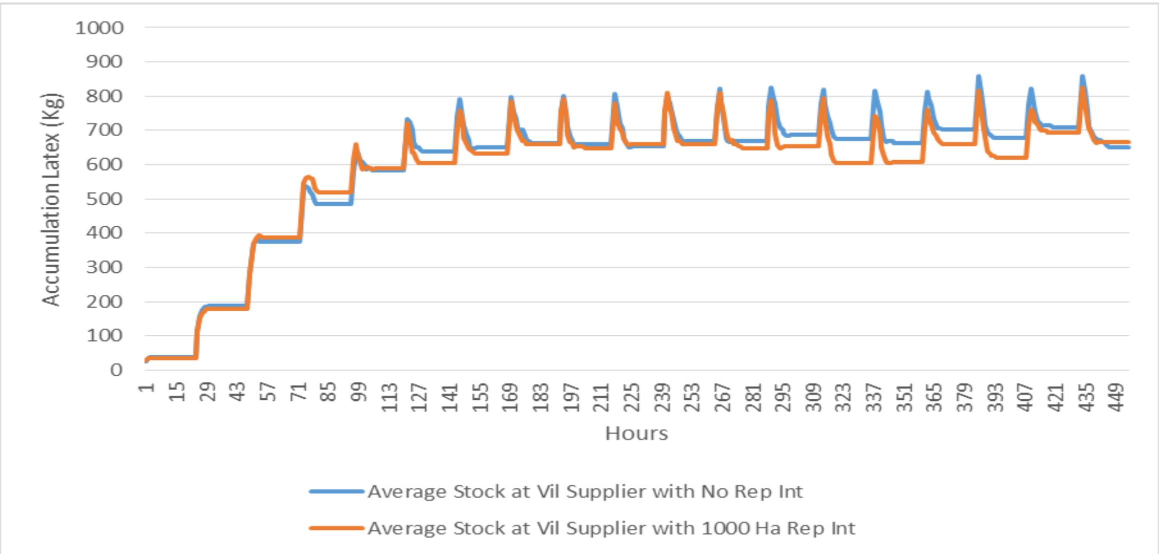


Figure 6.21 Impact of Replanting Scenarios on Average Stock of Village Supplier

The slight differences in average stock for district supplier occurred while replanting scenarios were applied to the network. Figure 6.22 shows that the average stock of the district supplier with a 1000 Ha replanting scenario is likely to mirror the average stock with no replanting scenario. There was no big difference in the average stock of the district supplier in Langkat district while replanting scenarios a rate between 100-1,000 Ha were implemented. This trend was a result of the impact of replanting scenarios only being perceived by some district suppliers and not by all district suppliers. Furthermore, owing to the large population of rubber smallholders in Langkat, reductions in productive rubber smallholders (owing to replanting) do not significantly reduce latex flow. However, impact is likely to increase concomitantly with the increasing rate of replanting scenarios.

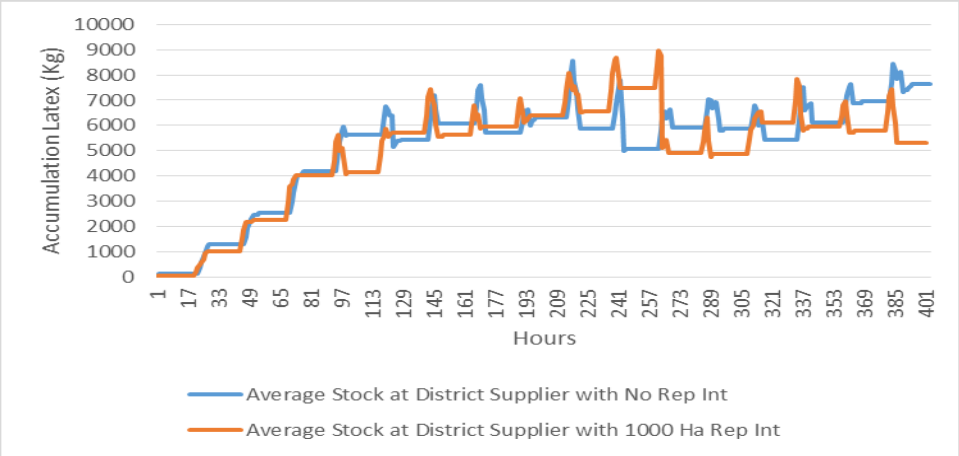


Figure 6.22 Impact of Replanting Scenarios on the Average Stock of District Supplier

6.3.2.2 Impact of Replanting Scenarios on the Average Income of Key Players

Income is essential for key players in the upstream natural rubber supply network. The majority of key players depend on income from latex production. This section presents a prediction of the income from the natural rubber supply that is received by key players. This income is calculated by multiplying the total flow of latex between key players with the latex price.

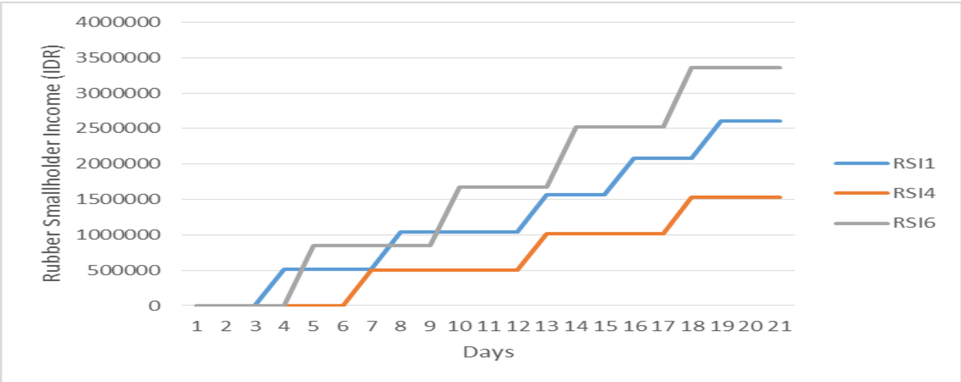


Figure 6.23 Rubber Smallholders' Income

Figure 6.23 shows the total income accumulated by rubber smallholder in 20 days. It can be seen that the simulation model generated different incomes for different rubber smallholders. This difference occurred because the total plantation area for each smallholder can vary. RS1 and RS4 can reach an income of more than IDR 2,500,000 in 20 days, while RS6 can only reach IDR 1,500,000 in 20 days.

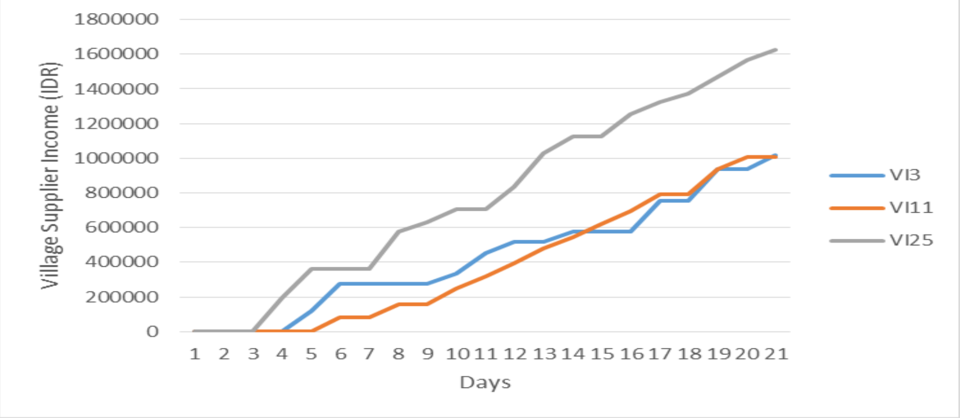


Figure 6.24 Income of Village Suppliers

The income of village suppliers and districts suppliers is calculated by multiplying the total latex flow with the selected profit chosen by key players. The probability of players to determine profit is calculated using the equation in Section 4.2.2 and Section 4.2.3. Figure 6.24 shows income predictions for three village suppliers in 20 days. It can be seen that, owing to the different capacities of village suppliers, the simulation models predict different incomes for different village suppliers. It can be seen that V3 produced a higher income compared with V11 and V25. The increase in income illustrates the flow of latex from village supplier to district supplier. For example, in Figure 6.24, the income of V3 increased in day 3, which indicated that on this day, V3 transferred latex to the district supplier.

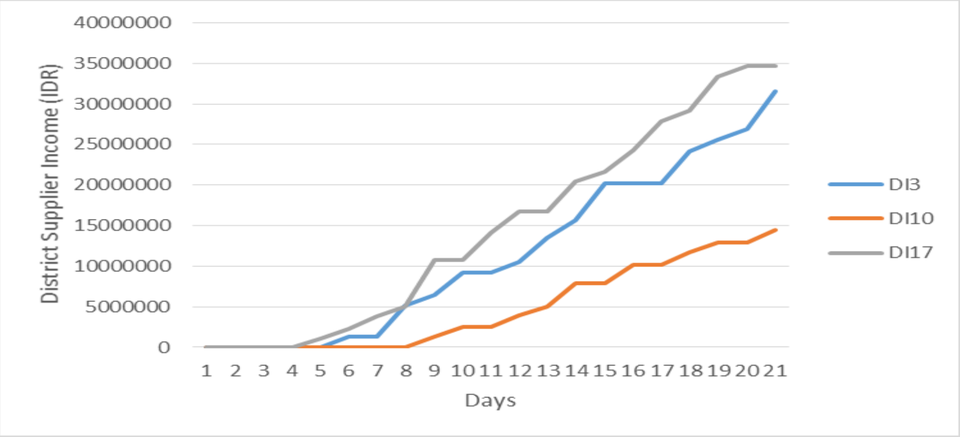


Figure 6.25 Income of District Suppliers

A similar situation can be observed for district suppliers. Figure 6.25 shows the income predictions for district supplier. It can be seen that the income for district suppliers can vary due to different capacities of supply for each district supplier. D3 and D17 can achieve incomes of more than IDR 30,000.000 while D10 can only reach an income of around IDR 15,000.000 in 20 days.

The other important data generated by agent-based simulation is average income. This data reflects the average total income received by all players in the simulation. This data can be used to predict the impact of replanting scenarios on the incomes of key players. Figure 6.26 shows the comparison of average incomes for village suppliers without replanting scenarios, and with 1,000 Ha replanting scenarios. It can be seen that there were no significant differences in the average incomes of village suppliers. The implementation of 1,000 Ha replanting scenarios was expected to have a light impact on the income of village suppliers.

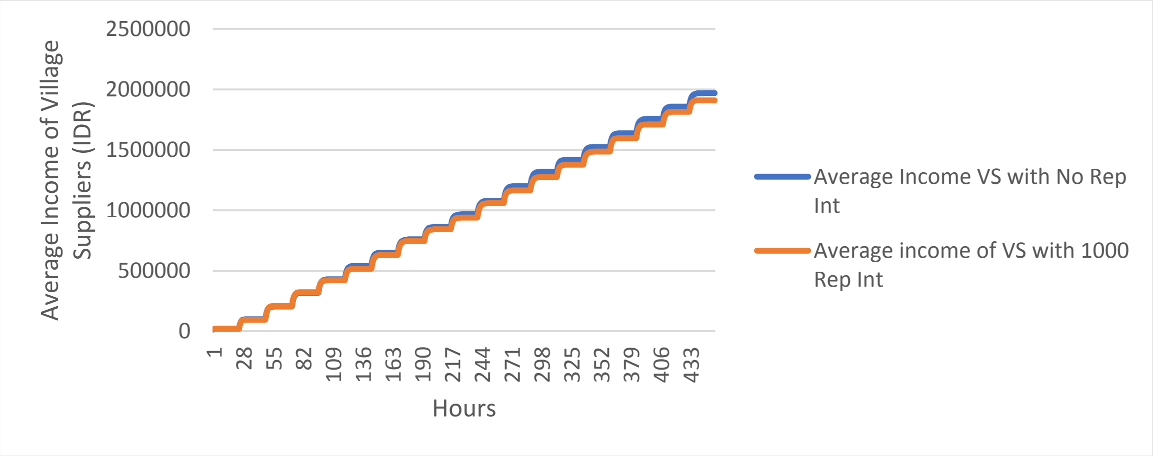


Figure 6.26 Impact of Replanting Scenarios on Average Income of Village Suppliers

A similar situation occurred for district suppliers. Figure 6.27 shows that there was no big difference between the average income of district suppliers without replanting scenarios, and those with 1,000 Ha replanting scenarios. It was expected that the implementation of replanting scenarios with 1,000 Ha rates would have a low impact on the incomes of district suppliers.

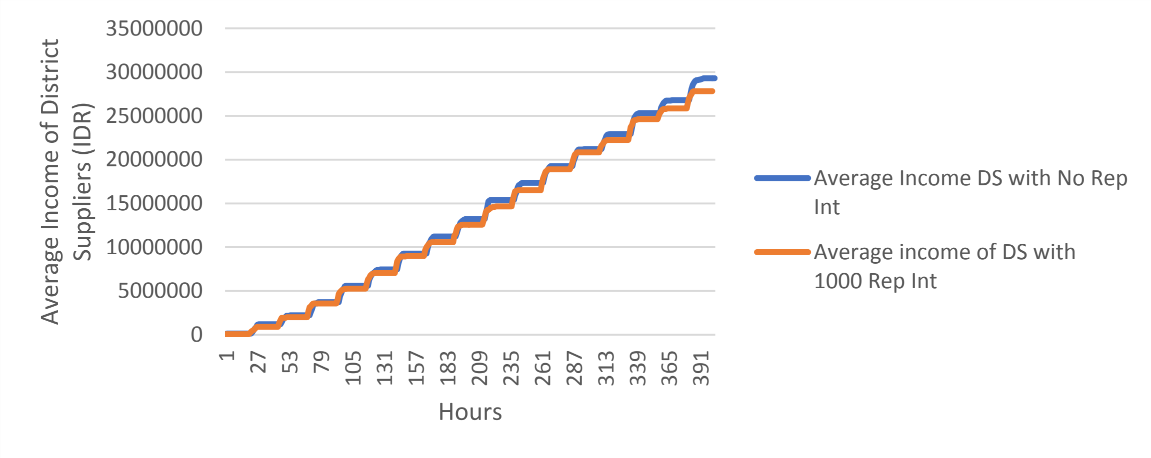


Figure 6.27 Impact of Replanting Scenarios on Average Income of District Suppliers

6.3.2.3 Impact of Replanting Scenarios on Average Travel Distance by Suppliers

This section introduces the impact of replanting scenarios on the average travel distance undertaken by suppliers. One main source of emission in the upstream natural rubber supply network comes from the transportation of latex from rubber plantations to primary processors. Agent-based models can generate the average distance travelled by suppliers to collect and deliver latex. The average distance data of the supplier can be used to predict emissions. Figure 6.28 shows the average distance travelled by village suppliers to collect latex from rubber plantations in the simulation. It can be seen that the average distance for village suppliers was around 1.5 to 2 km. Since village suppliers are located in the same villages as rubber plantations, the travel distance of village suppliers is less than 5 km.

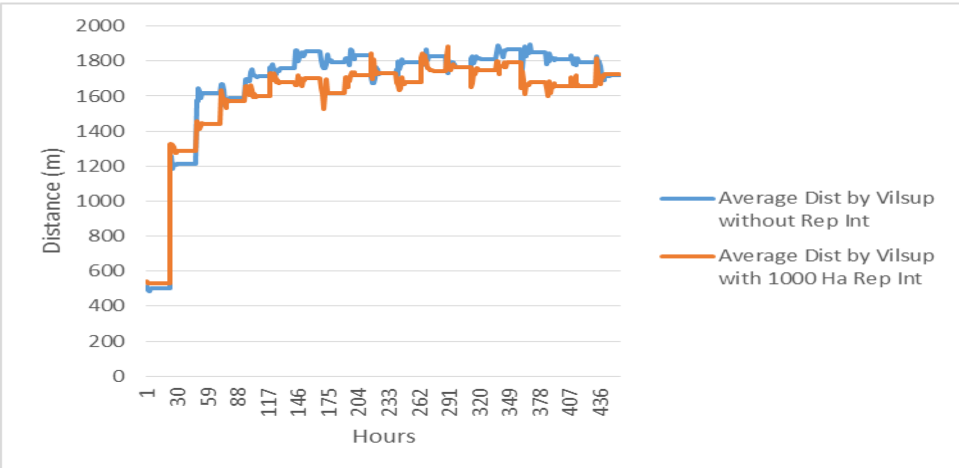


Figure 6.28 Impact of Replanting Scenarios on Average Travel Distance of Village Supplier to Collect Latex from Rubber Plantations

The average distance travelled by district suppliers will no longer be compared to that of village suppliers. This is because of the position of district suppliers in the capital of sub-districts. Some district supplies should collect latex in other sub-districts, which are the nearest sub-districts to where they are positioned. It can be seen in Figure 6.29 that the average distance for district suppliers collecting latex from village suppliers is around 4-8 km. The scattered nature of the district supplier population in several sub-districts influences the total travel distance to village suppliers. If the district supplier population is concentrated in one or two sub-districts only, the travel distances to collect latex from village supplier is likely to increase.

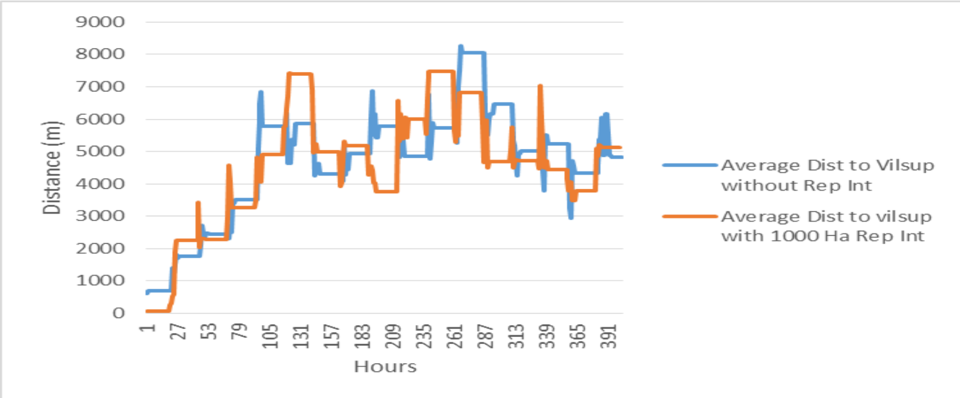


Figure 6.29 Impact of Replanting Scenarios on Average Travel Distance of District Suppliers in Collecting Latex from Village Suppliers

District suppliers also send latex to rubber traders who are located at primary processors. Figure 6.30 shows the average travel distance undertaken to send latex to primary processors in Langkat district. The location of primary processors in the simulation was set at Binjai district, which is outside of Langkat district. It was found that in simulation, the average distance for district suppliers was around 20-40 km. The location of district suppliers and primary processors influence the average distance to the primary processor. This variable influences the transportation cost, which in turn affects latex price.

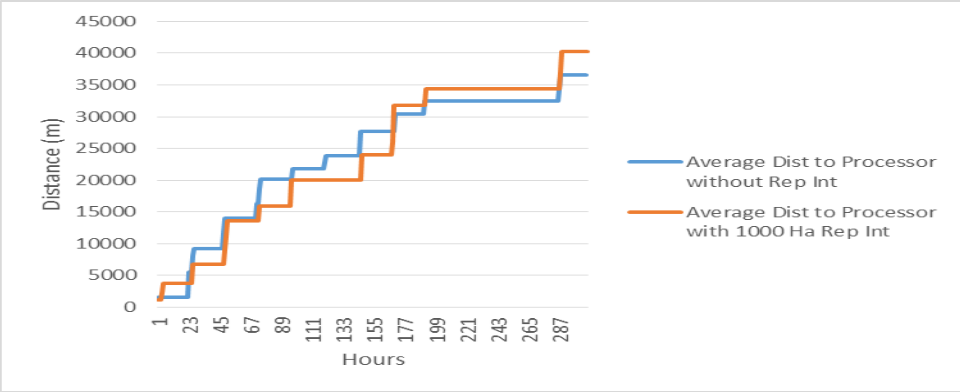


Figure 6.30 Impact of Replanting Scenarios on Average Travel Distance of District Suppliers in Sending Latex to Primary Processor

6.4 Composite Indexes and Optimum Replanting Scenario

The purpose of this section is to introduce the optimum replanting scenario for Langkat district determined from the application of composite indicators and dynamic programming models. This section is divided into two sections including Section 6.4.1, which presents the composite indexes of replanting impacts from the application of composite indicators model, and Section 6.4.2 which introduces the optimum replanting scenario from the application of the dynamic programming model.

6.4.1 Composite Indexes of Replanting Impacts

This section presents the composite indexes of replanting impacts for Langkat district produced from the application of the composite indicators model. The composite indicators model provides a trade-off between sustainability dimensions and indicators, and also converts the impacts of replanting scenarios into a composite index, which makes it easier to read and understand for policy makers in the natural rubber industry. The composite indexes have been produced through several steps including normalization, weighting, and aggregation.

6.4.1.1 Normalization Results

The normalization step links the targets of each indicator with the impacts of replanting scenarios, and converts the impact of replanting scenarios with different units into one similar unit. A distance-to-reference model was used as the main normalization method (see Section 5.3.4.1). This method shows the relationship between the desired target for each indicator and the impact of replanting scenarios. Table 6.4 shows the normalization results for the impact of replanting scenarios at year 3 (2016).

Table 6.4 Normalization of Replanting Scenario Impacts in Year 3 for Langkat District

Replanting scenarios (Ha)	Future Supply Index	Immature smallholder Index	Carbon Stock Index	CO_2 Sequestration Index	Smallholder's Population Index	Tapper's population Index
0	74	23	88	95	72	91
100	74	27	87	94	73	91
200	74	30	87	94	73	91
300	74	28	87	94	73	91
400	74	30	87	94	73	91
500	74	32	87	94	73	91
600	74	34	87	94	73	91
700	72	23	88	95	72	91
800	72	23	88	95	72	91
900	72	23	88	95	72	91
1,000	72	23	88	95	72	91

It can be seen in Table 6.4 that the impact of replanting scenarios was linked with targets for each indicator in Langkat district. For example, index 74 for future supply indicates that the implementation of 100 Ha replanting scenario is expected to produce 74% of the target supply. The future supply index has resulted from the comparison of latex production data from year 7 to year 12 in the simulation with the target of supply for Langkat district (in Table 6.4). Since the rubber tree starts to be productive six years after planting, latex production data in year 7 to year 12 is expected to deliver impacts of replanting scenarios in year 1 to year 5. There is no big difference in the future supply if the replanting rate between 0-600 Ha is applied in year 3. A similar trend occurs for the carbon stock index and CO_2 sequestration index. This is due to low levels of old plantations that can be replanted in year three. Using the index from the normalization step, the sustainability impacts of replanting scenarios are easier to understand for stakeholders.

6.4.1.2 Weighting Result

This section presents the weight of sustainability dimensions and indicators that are determined from the application of the weighting model. By determining the weight of each dimension and indicator, policy-makers have an opportunity to emphasise the dimensions and indicators that are considered more important than other dimensions and indicators. The weight of dimensions and indicators is used in converting the simulation result into the index. Defining indicators' and dimensions' weight has been executed using a budget allocation process through discussion with the expert panel in considering the current situation in North Sumatera Province. Table 6.5 shows the assigned weights for sustainability dimensions and indicators.

Table 6.5 Weight of Sustainability Dimensions and Indicators

Sustainability Dimensions	**Weight**	**Replanting Indicators**	**Weight**
Economy	60%	Future supply	60%
		Smallholders income	40%
Environmental	20%	Fertilizer rate	50%
		Carbon Absorption	50%
Social	20%	Population of smallholders	60%
		Population of Stepper	40%

The economic dimension’s future supply indicator is emphasized as more important than other dimensions and indicators due to the current situation in North Sumatera Province regarding reductions in natural rubber supply. Furthermore, the increasing awareness of stakeholders around environmental concerns has contributed the weight-setting of environmental dimensions and indicators. Furthermore, since rubber plantations brings benefits to social communities across the network, the social dimension and indicators need to be regarded as equal to the environmental dimension.

6.4.1.3 Aggregation Result

This section presents composite indexes that were produced from the application of the linear aggregation model. In this step, the trade-off between indicators and sustainability dimensions was ascertained by using the weights in Table 6.5 and the linear aggregating method (see Section 6.4.1.2). Table 6.6 shows composite indexes resulting from aggregation.

It can be seen from Table 6.6 that Langkat district faces a reduction in latex production. This trend can be observed from the index for replanting allocation with a rate of 0 Ha. This indicates that the natural rubber industry, which runs without receiving any additional intervention from the Indonesian Government, will face a reduction in its natural rubber supply in the next five years. In year 1, it is expected that no replanting scenarios will bring any positive impact to the natural rubber supply network. This is shown by the composite index from replanting scenarios where the different rate in year 1 is equal and less than the index for no replanting scenarios. A similar trend can be observed in year 2, where only replanting scenarios with rates of 100 Ha and 200 Ha are likely to produce higher indexes than those without replanting scenarios. In year 3 and year 4, replanting scenarios with rates between 200-600 Ha are likely to produce a higher index compared to other rates of replanting. In year five, higher replanting scenario rates, such as 800-1,000 Ha, produce a higher index compared to other rates of replanting.

Table 6.6 Composite Indexes for Impacts of Replanting Scenarios in Langkat District

Replanting scenarios allocation	**Composite Index**				
	Year 1 (2016)	**Year 2 (2017)**	**Year 3 (2018)**	**Year 4 (2019)**	**Year 5 (2020)**
0	77	71	66	64	64
100	77	72	67	65	66
200	76	72	68	67	68
300	76	71	68	67	68
400	76	71	68	67	69
500	76	71	68	68	71
600	76	71	69	69	72
700	76	71	66	67	70
800	76	71	66	67	71
900	76	71	66	67	72
1,000	76	71	66	68	73

Composite indicators have succeeded in converting impacts of replanting scenarios into composite indexes, which are easier to interpret, as well providing the trade-off between the impacts of replanting scenarios. Using composite indicators, stakeholders can emphasize dimensions and indicators that are more important in planning for replanting.

6.4.2 Optimum Replanting Scenario

This section introduces the optimum replanting scenario for Langkat district. This has been produced through the application of a dynamic programming model. The dynamic programming uses the Bellman optimum principle to define the optimum replanting scenario. Dynamic programming compares the impacts of replanting scenarios in order to define the optimum scenario per year. Dynamic programming uses composite indexes from the composite indicators model as initial data (Table 6.6). Following this, dynamic programming divides the problems into several sub-problems (stages). The optimum in sub-problems is influenced by the optimum value in the previous sub-problem (recursive function). For example, the optimum value in year 2 is calculated based on the optimum value in year 1. Using the equation in section 5.3.4.2, the following optimum table for each stage has been calculated.

Table 6.7 Optimum Impact for Stage 1 (Year1)

Total Allocation in Stage 1	**Optimum Impact in Year 1 (F_1**)**
0	**77**
100	77
200	76
300	76
400	76
500	76
600	76
700	76
800	76
900	76
1,000	76

Table 6.8 Optimum Impact for Stage 2 (Year2)

Total Allocation until Stage 2	**F_1****	**Impact of Replanting Scenarios Allocation at Year 2**											**F_2****
		0	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**100**	
0	77	**148**											**148**
100	77	148	**149**										**149**
200	76	147	149	149									149
300	76	147	148	149	148								149
400	76	147	148	148	148	148							148
500	76	147	148	148	147	148	148						148
600	76	147	148	148	147	147	148	148					148
700	76	147	148	148	147	147	147	148	148				148
800	76	147	148	148	147	147	147	147	148	148			148
900	76	147	148	148	147	147	147	147	147	148	148		148
1,000	76	147	148	148	147	147	147	147	147	147	148	148	148

Table 6.9 Optimum Impact for Stage 3 (Year3)

Total Allocation until Stage 3	**F_2****	**Impact of Replanting Scenarios Allocation at Year 3**											**F_3****
		0	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**100**	
0	148	214											214
100	149	215	215										215
200	149	215	**216**	**216**									**216**
300	149	215	216	**217**	216								**217**
400	148	214	216	217	217	216							217
500	148	214	215	217	217	217	216						217
600	148	214	215	216	217	217	217	217					217
700	148	214	215	216	216	217	217	218	214				218
800	148	214	215	216	216	216	217	218	215	214			218
900	148	214	215	216	216	216	216	218	215	215	214		218
1,000	148	214	215	216	216	216	216	217	215	215	215	214	217

Table 6.10 Optimum Impact for Stage 4 (Year4)

Total Allocation until Stage 4	**F_3****	**Impact of Replanting Scenarios Allocation at Year 4**											**F_4****
		0	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**100**	
0	214	278											278
100	215	279	279										279
200	216	280	280	281									281
300	217	281	281	282	281								282
400	217	281	282	**283**	282	281							**283**
500	217	281	282	**284**	283	282	282						**284**
600	217	281	282	284	284	283	283	283					284
700	218	282	282	284	284	284	284	284	281				284
800	218	282	283	284	284	284	285	285	282	281			285
900	218	282	283	285	284	284	285	286	283	282	281		286
1,000	217	281	283	285	285	284	285	286	284	283	282	282	286

Table 6.11 Optimum Impact for Stage 5 (Year5)

Impact of Replanting Scenarios Allocation at Year 5											**F_5****
0	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**100**	
350	352	353	352	353	**355**	**355**	352	352	351	351	355

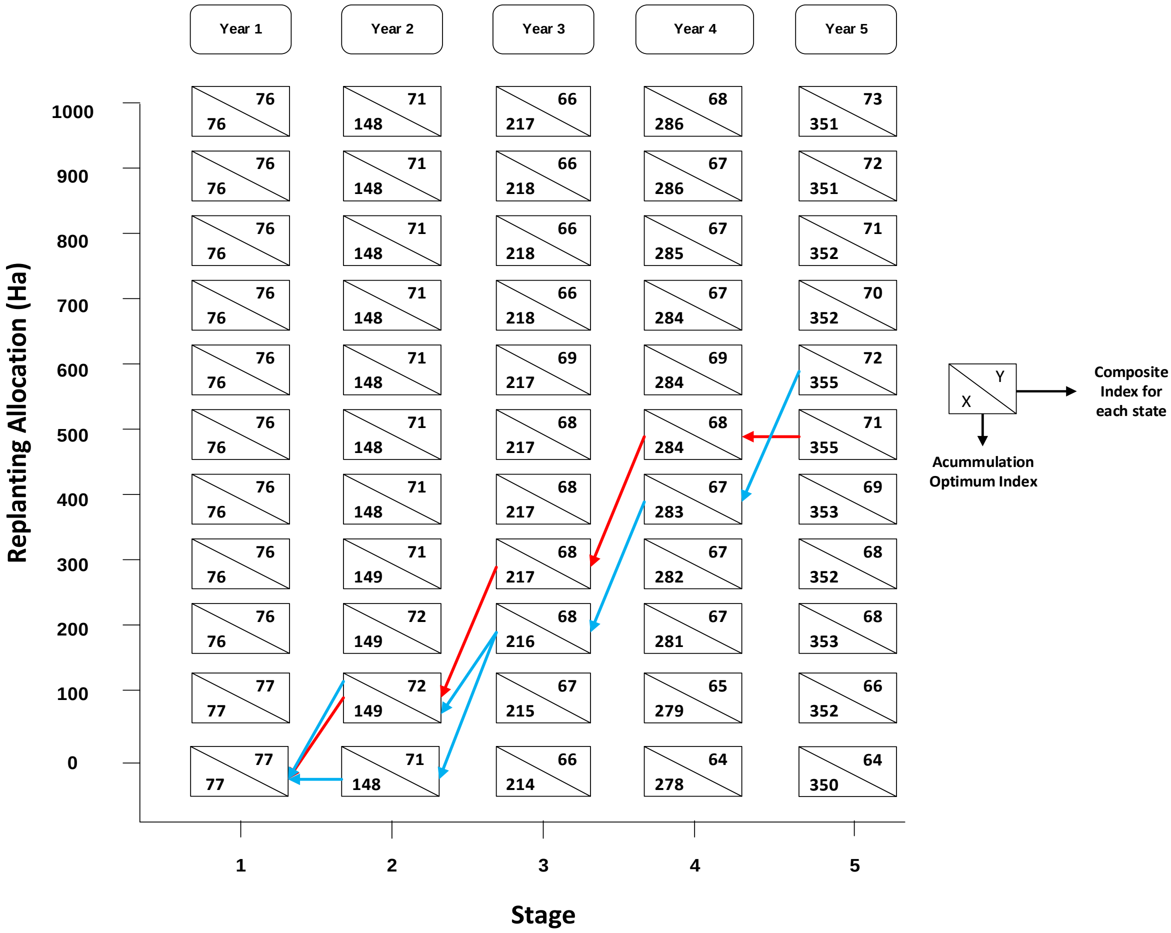


Figure 6.31 Optimum Allocation of Replanting Scenarios for Langkat District over Next 5 Years

Figure 6.31 summarizes and links the optimum value from every stage in the dynamic programming analysis. There are three scenarios for optimum allocation of replanting, resulting from the dynamic programming analysis. The optimum allocation of replanting scenarios was defined by conducting a backtracking process from the last stage to the first stage in the dynamic programming analysis (see the arrow symbol in Figure 6.31). The backtracking process was begun by defining the highest value at the last stage.

From Table 6.11, it can be seen that two replanting scenarios allocations have the highest value in stage five, including 500 Ha and 600 Ha. This indicates that 500 Ha and 600 Ha were the best rates for replanting scenarios in year 5. This means that from the total 1,000 Ha replanting allocation for Langkat district, there were only 500 Ha and 400 Ha allocation left for the four previous stages. The backtracking process from Table 6.10 subsequently indicates that the highest value for the total allocation 400 Ha and 500 Ha at stage 4 were 283 and 284. Both of these values were achieved by allocating 200 Ha at stage 4. This means that the best allocation for stage 4 was 200 Ha. From this calculation, there were only 200 Ha and 300 Ha allocations left for the three previous stages.

The next step required was to check the highest value for the total allocation 200 Ha and 300 Ha at stage 3 (refer to Table 6.9). For the allocation 300 Ha, the highest value was 217, while the highest value for allocation 200 Ha was 216. The value of 217 referred to the 200 Ha allocation, and the value of 216 referred to the 100 Ha and 200 Ha allocation. This means that there were two optimal replanting rates for stage three, including 100 Ha and 200 Ha. From this calculation, there were only 0 Ha and 100 Ha allocations left for the two previous stages.

The backtracking process for stage 2 in Table 6.8 indicates that the highest value for 0 Ha and 100 Ha total allocations were 148 and 149. The value of 148 referred to a 0 Ha allocation, while the value of 149 referred to a 100 Ha allocation. This means that there were two optimal replanting rates for stage two, including 0 Ha and 100 Ha. From this calculation, there was zero Ha allocation left for the one previous stage. For stage 1, the best allocation subsequently zero Ha. Table 6.12 shows the best combination of replanting allocations for the next five years in Langkat district.

Table 6.12 Scenario of Optimum Replanting Scenarios Allocation for Langkat District

Scenario	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Scenario 1	0	100	200	200	500
Scenario 2	0	100	100	200	600
Scenario 3	0	0	200	200	600

6.5 Discussion

The application of an approach using real-world data demonstrated the feasibility of system dynamics and agent-based simulation in representing the Indonesian upstream natural rubber supply network, and assessing the long-term sustainability impacts of replanting. The application of this approach also demonstrated the feasibility of composite indicators and dynamic programming in determining optimum replanting, by providing a trade-off between the three sustainability goals. The hybrid simulation models open wider opportunities for evaluating scenarios of rubber replanting without implementing it in real life. Moreover, the composite indicators model offers flexibility in emphasizing the sustainability dimension and indicators in the trade-off process based on the current condition of the supply network.

The application of this approach requires initial data. Some data were collected from government agencies, such as data related to the composition of rubber plantation areas and the population of key players. Some data were synthesized from literature, such as the parameters for simulation. Some data were determined by stakeholders, such as indicators that are used in developing replanting policy, targets of indicators, and weights of indicators. As a result, stakeholders' involvements were demonstrated in the process of applying this approach. Furthermore, the application of the approach requires computer hardware and software. The main challenge presented by the application is the time needed for simulation. The running of the simulation for assessing one scenario of replanting needs one to four hours, depending on the population of key players in a targeted district. To overcome this challenge, running more than one simulation simultaneously might be beneficial. However, this will require more computer hardware.

The assessment of replanting scenarios for several districts in North Sumatera Province indicates that impacts of replanting scenarios in every district can be different. An assessment of results for other districts can be observed in Appendix E. System dynamic results for Langkat district present reducing trend in the future supply after year 4. This may be caused by the total number of rubber plantations entering a low-productive phase being greater than the total of replanting started in year 4. On the contrary, in South Tapanuli district, an increase in the rubber supply was detected from year 1. This could occur due to the high amount of low-productive areas at the initial stage of simulation. However, in Deli Serdang district and Asahan district, significant fluctuations in supply were not detected. Future rubber supply in these districts seems to be steady at around 5,000 tons for the next 10 years. The reduction of supply is likely to occur in Deli Serdang and Asahan district after year 10, particularly, if there are no replanting scenarios applied in those districts. Furthermore, a stable condition is predicted for Simalungun district. Future supply for this district is expected to be steady at around 12,000 tons for the next 15 years. This condition presents a balance between total immature areas, productive areas, and low-productive areas, which is good for primary processors who receive supply from these districts.

Composite indicators translate data generated from simulation models into a single index, which is easier to understand by stakeholders. This index links the impacts of replanting with the desired targets for each indicator. Furthermore, the composite indicators provide a trade-off between sustainability impacts of replanting.

Stakeholders play a significant role in this stage by determining references and weights for each indicator. Based on the composite index in table 6.5 and appendix F, increasing replanting allocations will not always increase the value of indicators. Table 6.5 shows that, for Langkat district, while the allocation of replanting scenarios increased to more than 600 Ha for year 1, 2 and 3, the impact of replanting has been found to remain constant. This could have occurred due to the total of low-productive areas in Langkat district for next 3 years being less than 600 Ha. A similar condition has occurred in Deli Serdang and South Tapanuli District. On the contrary, in South Tapanuli district, replanting scenarios with rates more than 600 Ha can produce a higher index.

The single index provided by composite indicators becomes the main input for the dynamic programming model. The dynamic programming result shows that Langkat district requires different allocations of replanting in the next five years. The Langkat district was likely to require a low replanting rate in the first year to the third year, while needing a higher replanting rate in year 5. On the contrary, Deli Serdang and Simalungun districts were likely to demand more than 300 Ha replanting rates in the first three years. Furthermore, in South Tapanuli district, the best impact was gained by implementing higher replanting scenarios rates (more than 500 Ha) at year 4 and year 5. This result confirms that conditions of supply in targeted districts were different. To manage the capacity of supply from these districts, the different allocation of replanting scenarios for each district is therefore required.

The application of this approach has provided support for stakeholders in North Sumatera natural rubber industry in incorporating sustainability aspects for the formulation of replanting policies. Sustainability is not fully considered in current practices for formulating replanting policies in North Sumatera Province. The total areas that will be replanted in targeted districts are not determined based on the impacts of replanting on sustainability in the targeted districts. By using established hybrid simulation models, stakeholders can evaluate the impact of replanting scenarios on sustainability in targeted areas, such as impact on production, impact on carbon stock levels, and impact on the population of tappers. Furthermore, by using the established trade-offs and optimisation methods, stakeholders can determine the optimum scenario for replanting by conducting trade-offs between impacts of replanting.

Chapter 7
Contribution to Knowledge and Recommendation for Future Research

The upstream natural rubber supply network plays a vital role for the natural rubber industry by supplying raw material for primary processors and the downstream rubber industry. With an increasing demand for rubber products over the last ten years, it is expected that demand for natural rubber is likely to increase in the future. The Indonesian natural rubber industry is the main producer of natural rubber, supplying around 25% of the world's natural rubber supplies. This industry is facing a reduction in natural rubber supplies owing to many rubber plantation areas entering their low-productive phase. To maintain natural rubber supplies, strategic planning for replanting of these low-productive areas is required. In addition, given the increasing concerns related to environmental and social impacts of replanting, the strategic decisions for replanting need to consider these sustainability impacts in the planning process.

The aim of this research was to explore ways in which social, economic and environmental aspects of sustainability could be used to inform decisions related to the formulation of replanting policies. An approach for formulating sustainable replanting policies was established. The approach consists of a process, sustainability indicators and a strategic planning tool. The process and indicators were constructed based on information from literature and from case study investigations. The process highlighted the importance of assessing the sustainability impacts of replanting and the making of trade-offs between replanting impacts, while the indicators present the impacts of replanting on sustainability at district and individual level.

To support this process, a strategic planning tool was developed. The strategic planning tool combines hybrid simulations including system dynamics and agent based models with composite indicators and dynamic programming. The simulation models were developed to represent the Indonesian natural rubber supply network and to assess the impacts of replanting on the sustainability in the network. Furthermore, a composite indicators model was developed to support the trade-offs between the environmental, social and economic impacts of replanting and a dynamic programming model was developed to determine optimum replanting scenarios.

This research contributes to the need to promote sustainable agriculture as part of global sustainable development goals. One target aimed towards is "the implementation of agricultural practices and systems that increase productivity and production that help to maintain ecosystems, and that strengthen the capacity for adaptation to climate change, extreme weather, flooding and other disasters." (https://sustainabledevelopment.un.org/sdg2). This research supports stakeholders in the natural rubber industry in sustaining the natural rubber supply and incorporating the sustainability aspects into the formulation of replanting policies.

7.1 Contribution to Knowledge

The contribution to knowledge is presented here against the research questions.

Question 1: **What are key requirements for the assessment of the sustainability of replanting policies in the Indonesian natural rubber industry supply network?**

Two key requirements were identified: a need for a suitable sustainability assessment tool and associated indicators for use with such a tool. This research contributes sustainability indicators and an integrated assessment tool for assessing the sustainability of replanting policies in the Indonesian natural rubber industry supply network. Indicators for three dimensions of sustainability were identified by using case study investigation and review of literature. Since replanting brings significant effects on the region in general and on specific key players within a given region, these indicators are divided into two categories. The first category includes indicators at district level which are used to represent economic, social, and environmental impacts in a targeted district or region. The second category includes indicators at the individual level, which are used to represent the economic, social, and environmental impacts for key players in each targeted district.

The combination of system dynamics and agent-based modelling was developed as an integrated assessment tool for assessing the sustainability of replanting policies. System dynamics was used to generate sustainability impacts of replanting policies at the district level while an agent-based model was used to generate sustainability impacts of replanting policies at the individual level.

Question 2: **What are necessary characteristics of an integrated assessment tool for use in the assessment of the sustainability of replanting policies?**

A case study investigation identified replanting as an important event within the natural rubber production system that has a significant effect on three dimensions of sustainability: social, environmental and economic. Replanting is a critical decision performed by rubber smallholders. Replanting also influences the long term sustainability of the targeted network because replanting influences composition of plantation areas which in turn affects future supply and other sustainability performances of the supply network. Moreover, replanting brings effects to the whole region and also to individual players within the network. For this reason, integrated assessment tools for assessing the sustainability of replanting policies must be able to capture complexities of the natural rubber production systems including the behaviour of key players in the supply network and its impact on the three dimensions of sustainability. Tools also need to have the ability to generate long term sustainability impacts at aggregate level and individual level.

These characteristics were used to inform the development of an integrated assessment tool. This research contributes in establishing the combination of system dynamics and agent based model to meet the characteristics required for assessing the sustainability of replanting policies. The application of system dynamics and agent based modelling to assess replanting policies in North Sumatera Province demonstrated the characteristics of this integrated assessment tool.

Question 3: **How might an integrated assessment tool be used to inform decisions related to the formulation of replanting policies in the Indonesian natural rubber industry supply network?**

This research contributes a trade-off and optimisation method that uses the integrated assessment tool to inform decisions related to the formulation of replanting policies. The combination of composite indicators and dynamic programming was developed as a trade-off and optimisation method. Composite indicators were used to translate the sustainability impacts of replanting policies calculated by the integrated assessment tool into indices of replanting impacts. Dynamic programming was used to determine optimum replanting policies by using these indices.

The application of the trade-off and optimisation method to develop optimum replanting policies in North Sumatera Province demonstrated the ability of the method coupled with the integrated assessment tool to inform decisions related to replanting policies. Moreover, the other ability of the method was demonstrated including the ability to trade-off between impacts of replanting policies on three dimensions of sustainability and it provides the flexibility for planner to assign different priorities to the three dimensions of sustainability.

7.2 Achievements of Research

The achievements of research is displayed here against the research objectives

<u>Objective 1:</u> To identify approaches for developing sustainable supply networks from literature and the Indonesian natural rubber industry.

Sustainable supply networks can be developed by integrating sustainability into activities, processes and decisions across the supply network. Two important processes for achieving such integration within individual organisations from literature are the assessment of the sustainability impacts of policies, and the trade-off between those sustainability impacts in planning for policies (Seuring and Müller, 2008; Carter and Rogers, 2008). Current approaches to assessments and sustainability trade-offs focus on the triple-bottom-line evaluation of individual organisations' activities. Furthermore, current methods to support trade-offs tend to focus on one dimension of sustainability only rather than to trade-off between the impacts on key players or organisations within the supply network. However, these processes become more complex owing to characteristic of the supply network. Because the supply network consists of different organisations carrying out different activities, sustainability assessments should evaluate all activities from all organisations within the network, and results should reflect cumulative impacts from all organisational activities across the network. Furthermore, trade-off processes in supply networks not only occur between the three sustainability goals but also between the different sustainability goals of key players within the network. For example, various factors affecting the sustainability in the natural rubber industry arise through the supply network itself. As a result, more demand has emerged regarding the development of more nuanced approaches to the assessment process and sustainability trade-offs that span multiple organisations and activities in the natural rubber industry. This research contributes by establishing a sustainability assessment and trade-off method that takes account of this network perspective.

The supply network consists of several tiers with different activities, policies and decisions in each tier. Moreover, different industries need different supply network configurations owing to specific characteristic of those industries. As a result, different approaches are required to support the integration of sustainability into activities, processes and decisions in specific industry and each tier of the supply network (Hassini et al., 2012; Turker and Altuntas, 2014). For example, at the sourcing tier of an agricultural supply network, sustainability aspects are used to inform the decisions related to planting, harvesting and distributing. However, for natural rubber industry, particularly for the sourcing tier, there is little research to support the integration of sustainability into decisions or policies. This research contributes by presenting an approach for incorporating sustainability aspects to inform decisions in sourcing stage of natural rubber industry supply network.

Rubber plantations are an integral part of the natural rubber industry because they supply raw materials for later stages where latex is processed into rubber and converted into products. In the Indonesian natural rubber industry, from interviews with key stakeholders, replanting policies are nonetheless required to sustain natural rubber supplies from rubber plantations. This is due to the number of low-productive areas across the supply network, which has triggered a reduction in natural rubber supply. Replanting replaces low productive rubber trees with new high productive rubber trees. However to become fully productive rubber tree needs six years in their immature phase. This situation brings significant impacts into the sustainability of the supply network. Learning from literature and a case study indicated that effective planning of replanting is required and this planning needs to take into account critical risks resulting from replanting policies including medium, long term natural rubber supply and other sustainability impacts. However, the focus of current research lies on assessing the impact of rubber plantation expansion on sustainability. There is insufficient research to support the assessment and the planning of replanting from existing rubber plantations. This research contributes by establishing an approach that incorporates sustainability aspects in the formulation of replanting policies.

Objective 2: To develop a case study of the Indonesian upstream rubber supply network, including the identification of key questions and issues for the formulation of sustainable replanting policies.

Two conceptual models of the Indonesian upstream natural rubber supply network were constructed. The first one illustrates natural rubber production and its distribution system showing how replanting introduces a new cycle of rubber trees into plantations, and how it affects the composition of rubber plantation areas, as well as latex production and distribution. Based on this model, the formulation of replanting policy needs to consider the composition of rubber plantation areas within the supply network.

The second conceptual model shows the operations and the decisions of key players. It was found that several external factors affect the decisions of key players. For example, decisions of rubber smallholders with low productive areas to replant was found to be influenced by external factors including palm oil price, rubber seed price, the availability of rubber seed, and the availability of government aid. Based on this conceptual model, the formulation of replanting policies needs to consider how key players make decisions and what factors influence those decisions.

Discrete choice experiments were used to investigate external factors that influence the decisions of key players, as well as to generate a utility model for those decisions. Decisions made by three types of key players were modelled: the decision to replant and to give fertilizer for rubber smallholders, and the decisions to determine latex prices for village suppliers and district suppliers. Table 7.1 shows these decisions and factors that influence them.

Table 7.1 Decisions of Key Players and Influential Factors

Key Player	Decision	Statistically Influential Factors
Rubber smallholders	To give fertilizer	Fertilizer price and latex price
	To replant	Palm oil price, rubber seed price, availability of rubber seed, and availability of government aid
Village Suppliers	To determine latex price at village level	Dry rubber price at primary processors, distance of village suppliers to rubber smallholders' plantations, dry rubber content, and options around profit
District Suppliers	To determine latex price at district level	Dry rubber prices at the primary processor level, dry rubber content, the weight of latex, distance, total number of competitors, and options around profit

Objective 3: To identify requirements for the formulation of sustainable replanting policies in Indonesia's natural rubber supply network.

Four requirements were identified.

- A new process is required to link sustainability aspects of replanting with the formulation of replanting policies. Current processes in literature and Indonesian natural rubber industry are focused on using recommended clones of rubber trees and optimising planting density. Hence, those processes are inappropriate to use in formulating sustainable replanting policies because they only consider one aspect of sustainability i.e. productivity of plantation under the economic aspect.
- Indicators are required to quantify the impact of replanting policies on social, economic and environmental aspects of the supply network. Current indicators from literature are not suitable to be used in formulating replanting policies because they do not reflect the impacts of replanting.
- A strategic planning tool is required to link sustainability aspects with replanting policies. Current tools available in literature are not built specifically for supporting the formulation of sustainable replanting policies.

- The compositions of rubber plantation areas within the supply network, how key players make decisions and what factors influence these decisions need to be incorporated in formulating replanting policies. This is needed because what constitutes an optimal replanting policy varies over time depending on the life cycle of the current composition of rubber plantation areas and decisions of rubber smallholders with low productive plantations to replant.

Objective 4: To design and prototype an approach for formulating sustainable replanting policies that takes into account practical constraints such as availability of data, scope of area that will be covered, and performance criteria.

A new approach for formulating sustainable replanting policies was developed. The approach consists of a process, sustainability indicators and a strategic planning tool for formulating sustainable replanting policies. The process highlights four important steps: develop replanting scenarios, determine appropriate indicators, assess impacts of replanting scenarios, and determine optimum replanting scenario.

A case study and reviews of literature indicated that replanting activities in the upstream natural rubber supply network have several impacts on sustainability of the network as a whole. These impacts were translated into sustainability indicators. Under the economic dimension, five indicators were identified:

1. Latex production (kg or tonnes per annum): replanting influences latex production from the supply network because there is no production during immature phase after replanting.
2. Population of rubber smallholders with immature tree (people per annum): These smallholders are susceptible due to lack of income resulting from no production within immature phase.
3. Utilization of primary processors: this is a measure of the comparison between latex production and the total capacity of primary processors. Replanting can cause reduction in the utilization of primary processors because there is no production during immature phase.
4. Stock of latex accumulated by key players (kg per week): reduction of material flow owing to no production during immature phase can influence stock of latex accumulated by key players within the network.
5. Income of key players (IDR per week): reduction of latex stock accumulated by key players can influence income of key players.

Under the environmental dimension, four indicators were identified.

1. Carbon stock level (tonnes C per annum): this reflects the total amount of carbons that are stored in rubber trees within the supply network. Replanting

reduces the ability of the plantation to store carbon by replacing old rubber trees with immature trees, which store less carbon than older ones.

2. Carbon sequestration (tonnes CO_2 per annum): this reflects total amount of carbons that are absorbed from the air. Replanting reduces the ability of the plantation to absorb carbon by replacing old rubber trees with immature tree with low ability to absorb carbon.
3. Emissions from replanting and fertilizer (tonnes CO_2 e, CH_4 e and N_2O e per annum): the replanting activity itself is associated with emissions, such as those emitted by the burning process during replanting. Total emissions therefore increase with the level of replanting across the supply network. Furthermore, fertilizer is one main source of emission.
4. Average distance travelled by suppliers (meter per week): this reflects the total distance that is travelled during the distribution process from the rubber plantation to the primary processor. This indicator could be used to predict emissions during the distribution process. Replanting can reduce average travel distances by suppliers because many rubber plantations will be in immature phase and so not producing latex.

Under the social dimension, three indicators were identified.

1. Population of rubber smallholders (people per annum): replanting influences the population of rubber smallholders by preventing rubber smallholders from switching to other crops
2. Population of tappers (people per annum): replanting replaces the low productive rubber trees with non-productive ones. Within the immature phase, the tappers' service is not required, which can reduce population of tappers.
3. Population of suppliers (people per annum): the reduction of material flow within the network owing to no production within the immature phase can influence population of suppliers who act as an interface between smallholders and primary processors.

The strategic planning tool was developed to satisfy the requirements for formulating sustainable replanting policies in Objective 3. The strategic planning tool combines the hybrid simulations of system dynamics and an agent-based model with the composite indicators and dynamic programming. Simulation models were developed to represent the Indonesian upstream natural rubber supply network and to assess the impacts of replanting on the sustainability of the supply network. A composite indicators model was developed to support the trade-offs of replanting impacts and a dynamic programming model was established to determine optimum replanting policies. Simulation models were developed to implement conceptual models of the case study (see Objective 2).

To ensure that the strategic planning tool produced reliable results, a three-stage verification and validation process was applied. In the first stage, structural verification by an expert panel was used to evaluate the similarity of the computerized model with the conceptual model to ensure the computerized model reflected the real system. In the second stage, verification was arranged to remove errors from the computerized model as well as to ensure that the functions of the computerized model worked correctly. In the final stage, operational validity was established by comparing results from the tool with historical data and manual calculations. The verification and validation process provided opportunities for stakeholders to be involved in the development of the models and their implementation by generating feedback for both models. For example, an early version of the system dynamics models did not included external factors that influenced replanting rate. However, feedback from the expert panel indicated that the relationship between external factors and replanting rate is important and needed to be included.

Objective 5: To verify the approach by using it with target users to formulate sustainable replanting policies in the North Sumatera natural rubber industry.

An application of the approach using real-world data demonstrated the feasibility of the approach and the process for formulating sustainable replanting policies for North Sumatera natural rubber industry. Four important steps that were established in this research (listed under Objective 4) were conducted to formulate sustainable replanting policies. First step was to determine replanting scenarios. An expert panel of industry stakeholders was established and ten replanting scenarios for targeted districts in North Sumatera were agreed. Each scenario reflected allocation of low productive areas to be replanted over a 5-year period. Several constraints such as availability of resources and composition of rubber plantations were considered in determining the replanting scenarios. The second step was to determine indicators for use in formulating replanting policies. Indicators were selected by the expert panel by considering the current situation in North Sumatera. Six indicators (latex production, population of smallholders with immature land, carbon stock level, carbon dioxide sequestration level, population of rubber smallholders and population of tappers) were selected to be used in formulating replanting policies.

The third step was an assessment of sustainability impacts of the replanting scenarios. Hybrid simulations model were applied to assess these impacts on the sustainability of the supply network in five targeted districts. Impacts of replanting on sustainability at district and at individual levels were successfully generated by the hybrid simulation models. This step demonstrated the applicability of the system dynamics and agent-based simulation to assess the impact of replanting and to generate long-term sustainability impacts. The fourth step was to determine optimum replanting scenario. The composite indicators model was applied to support the trade-offs of replanting scenarios' impacts and the dynamic programming model was applied to determine optimum replanting scenario. A composite index of replanting impacts was successfully generated by the composite indicators model and an optimum replanting scenario was successfully identified. This step demonstrated the applicability of the composite indicators to support the trade-offs between the sustainability impacts of replanting, and the applicability of dynamic programming to determine the optimum replanting scenario. Finally, the application of the approach produced a recommendation of replanting for five targeted districts in North Sumatera. Table 7.2 shows this recommendation. The recommendation could be used by the Indonesian government and the rubber primary processor association (GAPKINDO) for formulating replanting policies for targeted districts.

Table 7.2 Recommendation of Replanting for Five Targeted Districts in North Sumatera Province Resulting from the Application of Approach

District	Recommendation of Replanting (in Hectares)				
	1 (2016)	2 (2017)	3 (2018)	4 (2019)	5 (2020)
Langkat	0	100	200	200	500
Deli Serdang	300	100	400	100	100
Asahan	0	100	300	300	300
Simalungun	300	300	100	200	100
South Tapanuli	0	0	0	400	600

7.3 Limitations of Research

Limitations of this research are categorized into four key areas: the scope of research, research method, data availability and scenario of simulation.

7.3.1 Scope

This research is focused on incorporating sustainability aspects in the formulation of replanting policies for Indonesia's natural rubber industry. Characteristics of Indonesia's natural rubber industry and the configuration of Indonesia's natural rubber supply network may differ across the natural rubber industry in other countries, as shown in Table 1.1. Characteristics of Indonesia's natural rubber supply network contribute to designing entities in the system dynamics simulation and to determining the agents/key players in agent-based simulation. The application of hybrid simulation models (system dynamics and agent-based) in assessing replanting impact in other countries would therefore require adjustments for variables in the hybrid simulation models. For example, one rotation of rubber plantation in Indonesia's natural rubber industry is 30 years, while in other countries (such as Thailand and Malaysia) one rotation is only 25 years. Furthermore, network structure In Indonesia, based on the geographical condition, generally consists of two types of suppliers between the plantation and the primary processor, while in other countries (such as Thailand and India), there is only one type of supplier between the plantation and primary processor.

7.3.2 Research Method

Using case studies as a research method has provided an in-depth investigation of the behaviour of key players in the upstream North Sumatera natural rubber supply network. This investigation has succeeded in determining significant factors affecting key players' decisions, as well as generating a utility model to predict those decisions. However, this utility model cannot be used to reflect all populations in Indonesia's natural rubber industry, and cannot be used to predict decisions of rubber smallholders in other provinces in Indonesia. This is due to factors affecting key players' decisions being different in other provinces in Indonesia. For example, in the North Sumatera Province, the main substitute crop for rubber is palm oil, hence the price of palm oil influences rubber smallholder decisions to replant their land. In other provinces, the main substitute crop for rubber may be different from that in North Sumatera Province. As a consequence, the implementation of hybrid simulation models for assessing replanting impacts in other provinces of Indonesia requires an adjustment in utility models, which reflect key players' decisions, particularly the utility models for replanting decisions and making fertilizer decisions.

7.3.3 Data Availability

The application of a strategic planning tool requires initial data such as total immature area, total productive area, total low-productive area, population of rubber smallholders, population of tappers, population of village suppliers, and population of district suppliers. A lack of these initial data contributes to reductions in the accuracy of assessment results. Furthermore, several parameters in the hybrid simulation models require data reflecting the current situation in a targeted district/area. For example, parameters of production rate for every phase in a rubber plantation's life cycle are generated from real production rates in a targeted district. Moreover, to achieve accuracy, agent-based simulation requires synthetic population data reflecting individual data from key players. For example, data related to the total area of plantations, the location of plantations for rubber smallholders, data related to the capacity of supply and location of supplier for village supplier and district supplier – all are types of synthetic population data.

For trade-offs and optimisation models, assessment results of different replanting scenarios are required as initial inputs. The optimum replanting scenario is defined based on the trade-off process between the sustainability impacts of replanting scenario. The optimum replanting scenario generated the highest sustainability impacts to the supply network. The sustainability impacts can be generated from various sustainability assessment models. Trade-offs and optimisation models cannot be applied without the existence of sustainability impacts from different replanting/planting scenarios.

7.3.4 Scenario of Simulation

The simulation experiment was focused on the investigation of the impact of replanting allocation on the sustainability of the targeted network with a view to identifying an optimum replanting allocation for the network. As a result, the simulation scenario was designed to achieve these objectives. In this scenario, replanting allocation was set as an independent variable and was modified during the simulation process while the indicators for the three dimensions of sustainability were set as dependent variables (see section 6.1 and 6.2). Although, the simulation model consists of many variables to represent entities and the links between those entities in the Indonesian natural rubber production and distribution system, other potential variables in the simulation model were set to be constant during the simulation process. This was done so that the impact of replanting allocation on sustainability indicators could be clearly observed.

7.4 Directions for Future Research

This research has contributed a new approach for developing sustainable replanting policies. The first possible future research direction is an implementation of optimum replanting scenarios in the supply network. The challenges that are found during implementation could be used to improve the approach. Then, this is continued by monitoring the real impacts of the implementation. The second possible future research lies on an application of the approach for other countries, such as Thailand, Malaysia, and India who also have major natural rubber industries. However, the application of the approach for supporting replanting in these countries requires further investigation. Investigations are mainly required for adjusting the conceptual model of natural rubber production and distribution, the configuration of the supply network, and the behaviour of key players. The life-cycle of rubber plantations in other countries might be different from Indonesia, too, as may be the constructions of supply networks. Furthermore, the opportunity is open for investigating the impact of other entities in the natural rubber production and distribution system on the sustainability of the supply network. This could be achieved by increasing the complexity of the simulation scenarios. For example, modifying the other variables in simulation model such as latex price, level of switching crops and availability of new plantations could increase the complexity of replanting scenario.

The approach outlined for developing replanting policy could be implemented for different crops, particularly for similar long-term crops such as palm oil and cocoa. However, further investigation is required to implement the approach for other crops, particularly regarding the adjustment of elements in the hybrid simulation models, such as the life cycle of crops, the configuration of supply network, and the behaviour of players. Another important issue that has not been covered by this research is uncertainty factors, which also reflects risk factors. Uncertainty factors such as weather, crop disease, and disaster have been found in the supply network, all of which influence its performance. Aligning uncertainty factors with the strategic planning tool requires further investigation.

The established hybrid simulations present an opportunity to support the supply network design so as to determine an appropriate number of suppliers, as well as to determine the appropriate location of suppliers within the supply network. The supply network design is one strategic decision requiring consideration for sustainability impacts. However, the implementation of established hybrid simulations to support the supply network design for the upstream natural rubber industry requires further exploration. Furthermore, the application of an agent -based simulation approach using a synthetic population will reflect the real material flow in the upstream natural rubber supply network. This can be used to enhance the current supply network design. However, further investigation is required, particularly in the development of a synthetic population of players in the upstream natural rubber supply network.

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Appendix A Interview Questions and Results

A.1 Interview Result for Stakeholders in North Sumatera Natural Rubber Industry

Interview has been performed to 8 participants which consisted of rubber primary processor association (GAPKINDO), Academics from University of North Sumatera and STIPAP, Researchers from Sungai Putih Rubber research centre, Government officer from Province Plantation agency and Seed Certification and Plant Protection agency.

No	Questions	Information Will Be Sought	Interview Result
1	What do you think about rubber supply from North Sumatera Province?	Opinion about current condition of North Sumatera Natural rubber industry	The rubber supply from rubber plantation in north Sumatera province has reduced significantly since five years (P1, P2, P3, P4, P5, P6, P7, P8). As a result, the primary processors in this area are lack of supply and have to reduce the production capacity into about 40-50% (P1, P8). The reasons for reduction of rubber supply are: • Many Plantations massively enter unproductive phase (P1, P2, P4, P7). There are 70000 Hectares of unproductive rubber plantation in 2011 (P7). This condition happened because majority of plantation in North Sumatera were opened in 1980-1988 by using the government programme (PIR). As the result, using maximum age of 25 for productive rubber tree, these plantations are entered unproductive phase since 2005 (P2). • Conversion into different types of seed mainly palm oil (P1, P2, P3, P4, P5, P6, P7). • Low Productivity of rubber smallholders Due to: 1. Smallholder did not use good seed for their plantation (P1, P2, P3, P5, P6). 2. Smallholders did not apply standard procedure for cultivation their plantation including to give fertilizer and to arrange the

			distance between rubber's trees. (P1, P2, P4, P6). 3. Smallholders did not apply standard procedure for rubber tree tapping (P1, P5, P6). • The government-replanting programme only covers small area of unproductive plantations (P3, P6, P7). • Low price of rubber has triggered the smallholder to stop the production by reducing or stop the tapping process (P3, P4, P5, P6, P7, P8).
2	Do you know who the key players in Indonesia rubber industry are?	Information about key player in Indonesia rubber industry	P1, P2, P3, P4, P5, P6, P8 indicate that the key players in Indonesia upstream natural rubber industry consist of: • Rubber smallholder is people who owned the rubber plantation • Village Supplier is people who locate at villages and directly buy latex to rubber smallholder • District Supplier is people who locate at district and buy latex from many village supplier. • Rubber Trader (Agent) is people who locate at primary processor and buy latex from many district supplier.
3	Do you think, what are the problems which are facing by key players in Indonesia rubber industry?	Identify the real problems	The problems are faced by key players are: • Many Plantations massively enter unproductive phase (P1, P2, P4, P7). There are 70000 Hectares of unproductive rubber plantation in 2011 (P7). This condition happened because majority of plantation in North Sumatera were opened in 1980-1988 by using the government programme (PIR). As the result, using maximum age of 25 for productive rubber tree, these plantations are entered unproductive phase since 2005 (P2). • Conversion into different types of seed mainly palm oil (P1, P2, P3, P4, P5, P6, P7). • Low Productivity of rubber smallholders Due to: 4. Smallholder did not use good seed for their plantation (P1, P2, P3, P5, P6. 5. Smallholders did not apply standard procedure for cultivation their plantation including to give fertilizer and to arrange the

			distance between rubber's trees. (P1, P2, P4, P6). 6. Smallholders did not apply standard procedure for rubber tree tapping (P1, P5, P6). • The government-replanting programme only covers small area of unproductive plantations (P3, P6, P7). • Low price of rubber has triggered the smallholder to stop the production by reducing or stop the tapping process (P3, P4, P5, P6, P7, P8). • Low quality of rubber smallholder product. This is because the smallholders do not use the standard coagulant for latex and mix their latex with strict material (P1, P2, P3, P4, P5, P6, P8). • Inefficient of rubber supply chain. This is indicated by long stage before reaching primary processor. The selling method between rubber smallholders with village supplier is based weight of latex. On contrary the selling method between rubber trader with primary processor is based dry rubber content (drc). As the result, rubber smallholders try to increase the weight of their latex in order to get higher income by mixing the pure latex with strict material (P4, P5, P6, P8). • The location of plantation is far from primary processor. This trigger high cost of transportation from plantations into primary processors (P1, P4, P6, P8). • Indonesia government apply the tax into rubber supplier and rubber smallholder. This has reduced the income of key players mainly when the rubber price is very low (P1, P8).
4	If you observe the current practices that implemented by key players in Indonesia rubber industry, Do you think the rubber supply from current	Opinion about the probability the current supply can be sustained which supported by current replanting program	Based on the current condition of rubber smallholders, the rubber supply cannot be ensured for next few years (P1, P2, P3, P4, P5, P6, P7, P8).

	plantation can be sustained?		
5	What are the key practices that influence the rubber supply?	Identify the activities and practices that can influence rubber supply	The key practices that influence the rubber supply are: 1. Managing Replanting of rubber plantation (P2, P3, P7). 2. Maintaining the rubber price at upstream natural rubber industry (P1, P3, P4, P6, P7, P8). 3. Availability of fund in government to support rubber industry and replanting (P1, P7). 4. Increasing productivity of rubber plantation (P2, P7). 5. Using the high quality and standard seed (P3, P6). 6. Good coordination and collaboration between Primary processors association, Government and rubber researchers (P3) 7. Forming the strong institutional of rubber smallholders such as small group or community smallholders in villages (P3, P4) 8. Increasing the mastery of cultivation technique for rubber smallholders (P4, P6). 9. Increasing quality of rubber product from smallholders (P4, P5) 10. Rubber smallholder accompaniment in replanting period is needed. The accompaniment is performed by researcher and instructor (P6).
6	Do you think the keys players in Indonesia rubber industry has been adopt the sustainable development in their current practices?	The integration of sustainable development in key player activities/ practices	There is no implementation of sustainable development in Indonesia upstream rubber industry (P1, P2, P3, P4, P5, P6, P7).
7	Do you think, what are the drivers/factors that can trigger the key players in Indonesia rubber industry to adopt the	Identify the driver for adopting/ implementing sustainable development	The drivers that can trigger key players to adopt sustainable development can be divided into three big area which are: Financial/ Economic Circumstances • Price of rubber at smallholder side (P1, P8) • Transportation cost (P4, P6) • Tax (P8)

	sustainable development?		• The supplier cost (P4) Regulatory Framework • Regulation about rubber supplier certification (P4, P8) • Regulation about rubber supplier tax (P1, P8) • Regulation about land conservation (P4) Stakeholder • Government (centre or local) can push the key players to adopt sustainable development by provide training and accompaniment to rubber smallholders (P1, P3, P6) • GAPKINDO (Rubber Primary Processor) can push the rubber smallholder to provide high quality rubber by rejecting or do not accept low quality of rubber (P3, P4). • Researchers can provide a transfer of standard cultivation technique to rubber smallholders (P3, P6).
8	Do you think what are the drivers require to change in Indonesia rubber industry by adopting sustainable development? (goals, process, culture, technology, infrastructure and people)	Identifying the changes that are required or demanded by drivers	Stakeholder push the key player to change in: • Adoption of standard tapping process (Process) (P1, P5, P6) • Adoption of standard cultivation technique (Process) (P1, P2, P4, P6) • Adoption of standard latex processing (using standard coagulant) (Process) (P3, P4, P5, P6) • Availability of high rubber quality seeds. (infrastructure) (P3, P6) • Availability of high quality seed producer and supplier. (infrastructure) (P6) • Availability of rubber research centre (infrastructure) (P2, P3) • Availability of Government programme in supporting natural rubber industry. (goal) (P1, P3, P6, P7) • Availability of regulation that manage replanting and sustainable development in natural rubber industry. (goal) (P1, P3, P4) • Availability of rubber smallholders groups and communities. (culture) (P3, P4, P6) • Availability of supplier certification. (process) (P1, P4, P8) • Availability of fertilizer with reasonable price. (infrastructure)

			• Maintaining the rubber price at smallholder's side. (goal) (P1, P2, P3, P4, P5, P6, P7) • Availability instructor (People) (P3, P6) • Availability of rubber supplier (People) (P8)
9	Do you think what are the factors that influence the successful of implementation sustainable development in Indonesia rubber industry?	Identifying the factor that might influence the implementation of sustainable development	1. Maintaining the rubber price at upstream natural rubber industry (P1, P3, P4, P6, P7, P8). 2. Availability of fund in Government to support rubber industry and replanting (P1, P7). 3. Good coordination and collaboration between Primary processors association, Government and rubber researchers (P3) 4. Forming the strong institutional of rubber smallholders such as small group or community smallholders in villages (P3, P4) 5. Rubber smallholder accompaniment in replanting period is needed. The accompaniment is performed by researcher and instructor (P6).
10	Do you think the current or initiative replanting planning doing by local government or centre government can secure the rubber supply for next 10 years?	Opinion about the replanting programme run by government and key player which is related with rubber supply	According to P7 total of non-productive plantation is around 70000 hectares on 2011. The current replanting programme in north Sumatra plantation agency is designed based on allocation of fund and district demand of replanting. The replanting fund is come from centre government and province government. There are average 500 hectares (ha) of replanting every year since 2012, which are supported by government. The replanting program is given to smallholder, which consist of provision of seeds, fertilizer and plant protection from fungus. Every smallholder is allocated 533 seeds for 1 hectare and maximum 2 hectare (P7). GAPKINDO (Primary Processor Association) also provide the rubber seeds for rubber smallholders with average amount 80.000 seeds (P1). Rubber smallholder have solicitudes about the cost of replanting (P1, P2, P5) and the failure of replanting due to fungus attack to rubber root (P3, P6). The second concern is about loss of income for five years until the

			plantation become productive (P1, P2, P3, P4, P5, P6, P7).
11	Do you think what kind of goals or objectives that should be had by Indonesia rubber industry to create successful replanting?	Identifying the factors in goal/objective that can influence replanting	the factors of goals that important to assess is seriousness of local government in supporting natural rubber industry by evaluating: • Strategic plan of local/ district government (P1, P2, P3) • Allocation of fund to natural rubber industry by local/ district government (P1, P7)
12	Do you think what kind of method/process that should be implemented in Indonesia rubber industry to create successful replanting?	Identifying the factors in method/process that can influence replanting	At process side, the factors that important to assess are: • Cultivation technique that implemented by rubber smallholder (P2, P3, P4) • Rubber tapping technique that implemented by rubber smallholder (P3, P4) • Rubber Processing technique that implemented by rubber smallholder (P2, P3, P4, P5, P6)
13	Do you think what kind of culture that should be had by key players in Indonesia rubber industry to create successful replanting?	Identifying the factors in culture that can influence replanting	At culture side, the factors that important to assess are: • Availability of smallholders group or community (P3, P4, P6) • Characteristic age of smallholders (P4) • Level of education from smallholders (P1) • Characteristic tribe or ethnic of smallholders (P6)
14	Do you think what kind of technology that should be had by Indonesia rubber industry to create successful replanting?	Identifying the factors in technology that can influence replanting	At technology side, factors that important to assess are: • Master ship of cultivation technique (P1, P2, P3, P4, P5, P6) • Master ship of rubber tapping technique (P3, P5, P6) • Master ship of rubber processing technique (P2, P3, P4, P5, P6) • Master ship of high quality seed production technique (P3, P6) • Master ship of rubber plant protection technique (P3, P4, P6)
15	Do you think what kind of infrastructure	Identifying the factors in infrastructure	At infrastructure side, factors that important to assess are:

	that should be had by Indonesia rubber industry to create successful replanting?	that can influence replanting	• Composition of rubber plantation based on age of tree and seed source (P1, P2, P3, P4, P5, P6, P7) • Availability of seed producer and supplier (P1, P3, P4, P5) • Availability of fertilizer supplier (P3, P4, P5) • Availability of primary processor (P6) • Availability of research rubber centre (P2, P3) • Availability of Replanting equipment (P2, P5) • Availability of government plantation agency (P1, P7) • Availability of road to access rubber plantation (accessibility) (P6)
16	Do you think what kind of human resources that should be had by Indonesia rubber industry to create successful replanting?	Identifying the factors in human resource that can influence replanting	At human resource side, factors that important to assess are: • Availability of rubber instructor (P1, P2, P3, P4, P5, P6, P7) • Availability of rubber supplier (P1, P4) • Availability of rubber researchers (P2, P3)
17	Do you think, what are the impacts of replanting into environment?		Small impact to the surrounding (environment), can be neglected if the replanting run in proper way and small scale (P1, P2, P3, P4, P5, P6)
18	Do you think, what are the environmental indicators that can be used to assess the implementation of replanting programme?	Identifying the selected environmental indicators to be fit with assessment model	• Carbon absorption (P1, P2, P3, P4, P5, P6) • Level of using fertilizer (P3)
19	Do you think, what are the impacts of replanting into social and community?		The main impact of replanting is the seeds producer will be growth due to high demand of seed (P2, P3). The replanting will open opportunity for people to work during replanting (P1, P2, P4).

20	Do you think, what are the social indicators that can be used to assess the implementation of replanting programme?	Identifying the selected social indicators to be fit with assessment model	• Growth of seed producers (P2, P3) • Worker utilization (P1, P2, P4) • Level of poverty (P4)
21	Do you think, what are the impacts of replanting into economic situation/ condition of key players in Indonesia rubber industry?		The main impact of replanting is loss of smallholders' income. Reduction of rubber supply is significant impact and need to consider if replanting is applying in big scale (P1, P2, P3, P4, P5, P6)
22	Do you think, what are the economic indicators that can be used to assess the implementation of replanting programme?	Identifying the selected economic indicators to be fit with assessment model	• Rubber supply (P1, P2, P3, P4, P5, P6, P8) • Composition of productive and unproductive land (P1, P2, P3, P4, P5, P6, P8) • Smallholder income (P1, P2, P3, P4, P5, P6, P8) • Rubber supplier income (P4, P8) • Amount of smallholder that implement the replanting (P1, P2, P3, P4, P5, P6) • Amount of smallholder apply mix crop during immaturity of rubber tree (P3, P4, P5)

Note:

P1 = Participant 1which is executive secretary from GAPKINDO (Primary Processor Association)

P2 = Participant 2 from which is Rubber researcher at Sungai Putih Rubber Research Centre

P3 = Participant 3 from which is Rubber researcher at Sungai Putih Rubber Research Centre

P4 = Participant 4 which is Academic from University of North Sumatera

P5 = Participant 5 which is Academic from STIPAP (School of Plantation)

P6 = Participant 6 which is government officer in Unit of Seed Certification and Plant Protection

P7 = Participant 7 which is government officer in North Sumatera Plantation Agency

P8 = Participant 8 which is Member of GAPKINDO

A.2 Interview Result for Rubber Smallholders

During Mid November- Mid December 2015, 4 rubber smallholders have been interviewed. The purposes of interview are to determine the activities of rubber smallholder, to define the decision that have to take by rubber smallholders and to define the factors that influence rubber smallholder in making decision.

No	Questions	Information Will Be Sought	Interview Result
1	Could you please tell me your activities as rubber smallholders?	Identify the activities of smallholders	The activities which are done by rubber smallholder consist of: • Prepare the land for planting rubber tree (the activities will be different for new plant with replant) (P3) • Prepare the seeds (P3) • Plant the seeds (P3) • Giving the fertilizer and cleaning the rubber plantation (P1, P2, P3, P4) • Tapping rubber tree (P1, P2, P4) • Giving the coagulant and collecting lumps (P1, P2, P4) • Selling lumps to rubber supplier (P1, P2, P4)
2	Do you think, what are the factors that will influence you in making decision about replanting?	Factors influence decision making for replanting	There are three factors which influence the smallholder in making decision about replanting including: • Average price of rubber at plantation • Replanting cost which is costly due to mechanization of replanting process • Probability to get fungus attack due to unfinished land clearing
3	What kind of seeds did you use for your plantation?		The smallholder did not know about the seed that have been used due to age of their plantation. P3 has been performed the replanting and using PB260 as seed for his plantation.
4	Do you think, what are the factors that will influence you in	Factors influence decision making for selecting seed	The selection of seeds consider: • Source of seed • Quality of seed

	selecting seeds for your plantation?		• Advantage of seed such as quick to be productive
5	What kind of fertilizer did you use for your plantation?		Urea fertilizer and Hcl fertilizer
6	Do you think, what are the factors that will influence you in selecting fertilizer for your plantation?	Factors influence decision making for selecting fertilizer	Type of fertilizer is given based on the demand of rubber tree for example urea fertilizer is given to increase the amount of leaf. The decision of smallholder to give fertilizer into plantation.
7	Do you use labour as stepper in your plantation?		The smallholder use labour from the citizen who live near the plantation. Usually for 1 hectare plantation will need 1 labour for tapping the rubber tree. The working time of labour is started from 5 am until 11 am. Usually stepper is paid based on percentage of rubber sales for example stepper will be paid 30% of daily rubber sales (P1, P2, P3, P4).
8	Do you think, what are the factors that will influence you in choosing stepper for your plantation?	Factors influence decision making for choosing stepper	Smallholder will choose the stepper based on: • The location of stepper (P1,P2, P3) • Skill of stepper (P1, P2, P3, P4) • Cost of stepper (P1, P2
9	What kind of rubber are you producing?		Majority of smallholder produce lumps and slabs as product of their plantation. Lump is latex that is coagulated in cup. Slab is latex that coagulated in block shape. Only plantation owned by government and private company with big square area produce latex (fluid form).
10	Do you think, what are the factors that will influence you in selecting the type of rubber for your plantation product?	Factors influence decision making for selecting the type of plantation product	Smallholder produce lumps and slabs because it is easy to produce and not required complex equipment.
11	How do you sell your rubber product from your plantation?	The way of sell the plantation product	The lumps or slabs are collected for one week. Smallholder will sell their product at least once a week through rubber supplier.

12	Do you think, what are the factors that will influence you in selecting supplier for your latex?	Factors influence decision making for selecting suppliers/ channel	The decision of selecting supplier is based on location of plantation. If the location of plantation is far away from capital of district, village supplier will collect the rubber in plantation. Smallholder with production less than 500 kg will sell their product to village supplier. Smallholder who owned big plantation, around 2-10 hectare, with production more than 500 kg will sell to district supplier directly. The smallholder will choose the supplier who offer the highest price

A.3 Interview Result for Village Suppliers

During Mid November- Mid December 2015, 2 village collectors have been interviewed. The purposes of interview are to determine the activities of village collector, to define the decision that have to take by village collector and to define the factors that influence village collector in making decision.

No	Questions	Information Will Be Sought	Interview Result
1	Could you please tell me your activities as Village collector, district supplier and rubber traders?	Identifying the activities and practices which are done by village collector, district supplier and rubber traders	At certain time, every week for example on Saturday or Sunday, village collector will contact rubber smallholders to ask about their latex. Village supplier will offer the price for the latex. If rubber smallholder agrees with the price, village collector will visit their plantation and collect their latex with motorcycle. In every village, usually, rubber smallholders collect latex every two days from plantation and accumulate latex for one week. Every village where many rubber plantations exist has different time to sell the latex. For example, one village will sell latex in Monday but the other village will sell latex on Thursday. As the result, the operation time of village collector will be differed which depend on when rubber smallholders sell their latex in that village.

2	How large the area that you can cover in order to get the latex supply?	The coverage area of village collector, district supplier and trader while searching the source of latex?	The participants indicate that the covering area to find latex is limited to one village where the village collector lived. The covering area is on radius of 10 Km
3	How large the area that you can cover in order to distribute/supply your latex?	The coverage area of village collector, district supplier and trader while searching the destination of latex?	After getting latex from rubber smallholders. Its will be accumulated in village collector’s house. Then, it will be collected by district supplier in the same day, might be in afternoon or night.
4	Do you think, what are the factors that will influence you in determining the price for latex?	Factors influence decision making for determining the price	According to participants, the price at village level will be determined by considering the price at primary processor, quality of latex, quantity of latex, distance to smallholder’s plantation and total of village collectors exist in that village
5	Who are the sources for your latex?		All rubber smallholders exist in village will be targeted as sources for latex.
6	Do you think, what are the factors that will influence your decisions in selecting sources for your latex?	Factors influence decision making for deciding where to get the latex	All participants indicate that distance to source of plantations and relation with rubber smallholder as factors in selecting sources for latex. Moreover, one participant indicates that accessibility to plantation source as factor that influences in selecting sources.
7	Who are the destinations for your latex?		District supplier who operate in the village
8	Do you think, what are the factors that will influence your decisions in selecting destinations for your latex?	Factors influence decision making for deciding where to supply the latex	Price of latex that offered by district supplier and good relationship with district supplier.
9	What kind of transport that you use in your operation as supplier?		Motorcycle with capacity 50-100 Kg for placing latex
10	How much latex that you can receive?		500 Kg – 1000 Kg per week

11	What are the factors that will influence your decision when to receive latex supply?	Factors influence decision making for deciding the time when receive the latex	The time to receive latex will follow when rubber smallholders sell their latex.
12	How much latex that you can supply?		All latex that has been received will be supplied. 500 Kg – 1000 Kg per week.
13	What are the factors that will influence your decision when to supply the latex to your? (Capacity of warehouse, price of latex, capacity of transport)	Factors influence decision making for deciding the time when supply the latex	All latex will be supplied in same day with receiving latex. This is because risks resulting from fluctuation of latex price every day and limitation of money to buy latex from rubber smallholders.

A.4 Interview Result for District Suppliers

During Mid November- Mid December 2015, 3district suppliers have been interviewed. The purposes of interview are to determine the activities of district supplier, to define the decision that have to take by district supplier and to define the factors that influence district supplier in making decision.

No	Questions	Information Will Be Sought	Interview Result
1	Could you please tell me your activities as Village collector, district supplier and rubber traders?	Identifying the activities and practices which are done by village collector, district supplier and rubber traders	District supplier has position in district. Main activities for district supplier are to find latex from villages and other district. Latex from village collector is collected by district supplier. District supplier will collect latex from many village suppliers from different villages. District supplier has operation time every day. District supplier will offer a price to village collector and if village supplier agrees with the price, district supplier will come to the village to collect the latex. After collecting latex from different village and reaching the maximum capacity of truck, latex will be directly sent to primary processor.

2	How large the area that you can cover in order to get the latex supply?	The coverage area of village collector, district supplier and trader while searching the source of latex?	According to participants, the covering area for finding latex is mainly focus on village inside the district where they lived and village inside the nearest district to the district where district supplier lived. The covering area for district supplier is in radius between 0 to 100 km
3	How large the area that you can cover in order to distribute/supply your latex?	The coverage area of village collector, district supplier and trader while searching the destination of latex?	According to participants, the accumulated latex from many villages will be supplied to primary processor, which located nearest to the district where they lived.
4	Do you think, what are the factors that will influence you in determining the price for latex?	Factors influence decision making for determining the price	The price at interaction between district supplier and village collector will be determined based on the price at primary processor, quality of latex, quantity of latex, distance between location of village collector and primary processor, transportation cost, availability of latex from that village and total of district suppliers who operate in same area (villages).
5	Who are the sources for your latex?		Village suppliers from different villages
6	Do you think, what are the factors that will influence your decisions in selecting sources for your latex?	Factors influence decision making for deciding where to get the latex	Amount of latex offered by village supplier, distance from village collector's location to primary processor and accessibility to village collector's location
7	Who are the destinations for your latex?		The nearest primary processor from district supplier's position.
8	Do you think, what are the factors that will influence your decisions in selecting destinations for your latex?	Factors influence decision making for deciding where to supply the latex	The distance to primary processor. Long distance will cause high transportation cost and risk. The relationship with primary processor will influence in selecting destination target for latex.
9	What kind of transport that you use in your operation as supplier?		Truck with capacity 5-10 Ton

10	How much latex that you can receive?		Depend on availability of latex supply, total of district suppliers exist in same location and availability of money. Currently, district supplier has received 5 – 50 ton per week
11	What are the factors that will influence your decision when to receive latex supply?	Factors influence decision making for deciding the time when receive the latex	The operation time of district supplier will follow the schedule of village. Every village will have different time to supply latex.
12	How much latex that you can supply?		The amount of latex that can be supplied is depended to the amount of latex that have succeeded to buy from village collectors
13	What are the factors that will influence your decision when to supply the latex to your? (Capacity of warehouse, price of latex, capacity of transport)	Factors influence decision making for deciding the time when supply the latex	After accumulating latex from different village collectors and reaching capacity of truck, latex will be sent directly to primary processor in the same day.

A.5 Interview Result for Rubber Traders

During Mid November- Mid December 2015, 2 rubber traders have been interviewed. The purposes of interview are to determine the activities of rubber trader, to define the decision that have to take by rubber trader and to define the factors that influence rubber trader in making decision.

No	**Questions**	**Information Will Be Sought**	**Interview Result**
1	Could you please tell me your activities as Village collector, district supplier and rubber traders?	Identifying the activities and practices which are done by village collector, district supplier and rubber traders	Rubber trader is located at primary processor. The main activities of rubber trader are to receive latex from district suppliers, which come from different districts. Rubber trader will pay amount of latex that is accumulated by each district supplier. Rubber trader then will oversee the process of accumulated latex by primary processor. The process consists of weighing the quantity of latex, measuring the dry content of latex, and

			checking the quality of latex. After these processes, primary processor will transfer the payment to rubber trader. The payment is calculated based on dry rubber content and quantity of latex (in Kg).
2	How large the area that you can cover in order to get the latex supply?	The coverage area of village collector, district supplier and trader while searching the source of latex?	Rubber trader will receive latex from all district in North Sumatera Province. Even if rubber supply from North Sumatera province is not enough, the supply from nearest province is obtained. Most of latex supply is come from nearest district to primary processor's location.
3	How large the area that you can cover in order to distribute/supply your latex?	The coverage area of village collector, district supplier and trader while searching the destination of latex?	Rubber trader distributes latex only for one primary processor. Each primary processor will have more than one rubber trader in order to fulfil the latex demand.
4	Do you think, what are the factors that will influence you in determining the price for latex?	Factors influence decision making for determining the price	The price is determined based on primary processor's pricing. Rubber trader only takes certain amount for each kg of latex.
5	Who are the sources for your latex?		District Suppliers from different districts
6	Do you think, what are the factors that will influence your decisions in selecting sources for your latex?	Factors influence decision making for deciding where to get the latex	Rubber trader determines their sources based on availability of latex from location of source, quality of latex and distance between source and primary processor.
7	Who are the destinations for your latex?		Primary processor
8	Do you think, what are the factors that will influence your decisions in selecting destinations for your latex?	Factors influence decision making for deciding where to supply the latex	Rubber traders are allowed to supply latex after getting license from primary processor and permit from local government.
9	What kind of transport that you use in your operation as supplier?		No transport mode is needed. This is because, rubber trader only receive latex at primary processor. Transportation to

			primary processor is under district supplier responsibility.
10	How much latex that you can receive?		Every rubber trader normally receive latex from district supplier around 50 Ton until 100 Ton per week.
11	What are the factors that will influence your decision when to receive latex supply?	Factors influence decision making for deciding the time when receive the latex	Rubber trader receives latex every day. This is because; delivery schedule of district supplier could be different between districts.
12	How much latex that you can supply?		Every rubber trader normally supply latex to primary processor around 50 Ton until 100 Ton per week.
13	What are the factors that will influence your decision when to supply the latex to your? (Capacity of warehouse, price of latex, capacity of transport)	Factors influence decision making for deciding the time when supply the latex	After receiving latex from district suppliers, rubber trader will directly ask primary processor to process latex by weighing the quantity, measuring the dry rubber content and checking the quality of latex.

Appendix B Discrete Choice Questionnaires

B.1 Development of Discrete Choice Questionnaires

Discrete choice questionnaire was developed based on influential factors that have been found in qualitative phase. There are there steps in developing discrete choice questionnaire including determining factors levels, designing discrete choice experiment and validating the questionnaire.

B.1.1 Designing factors levels

Factors Levels for Decision to Give Fertilizer and Decision to Replant

Based on information at qualitative phase, for decision to give fertilizer, there are four factors influencing this decision, which are latex price (Kg), fertilizer price, availability of fertilizer and impact of fertilizer. Factors level for latex price is defined based on current latex price in North Sumatera Province. The current price is IDR 5,000 per Kg wet latex. Hence, this is set as lowest latex price. Then interval of IDR 2500 is used to define other levels for this factor. Factor level for fertilizer price is defined based on current fertilizer price in North Sumatera Province. The current price is IDR 300,000 per 50 Kg for Non Subsidized fertilizer and IDR 120,000 for 50 Kg subsidized fertilizer. Furthermore, in some area in North Sumatera, fertilizer is available only at certain time for example only in certain month, while in other area fertilizer is available all the time. In term of impact of fertilizer, current literatures indicate that fertilizer could improve rubber tree production from 10% until 30%.

For decision to replanting, there are eight factors influencing this decision. First factor is latex price. This factor has four factor levels including IDR 5000, IDR 7500, IDR 10.000 and IDR 12.500. IDR 5000 is current price of latex in North Sumatera and is used as basis for designing factor levels. Second is another popular crop price. In this research, popular crop in North Sumatera is palm oil. Hence, palm oil price is used as factor level. There are four levels which are IDR 1000 (current price), IDR 2000, IDR 3000, and IDR 4000. Third factor is rubber wood price. There are four levels for this factor including no price, IDR 2,500,000, IDR 5,000,000 and IDR 7,500,000. This is price for rubber wood from 1 Ha rubber plantation. Approximately, from 1 Ha, 300-400 bar rubber wood can be sold. Fourth factor is rubber seed price. There are two levels for this factor, which are IDR 7000 per seed and IDR 13,000 per seed. Fifth factor is availability of rubber seed. Due to limited rubber producer in North Sumatera, in some area, rubber seed is available in certain time while in other area rubber seed is available all the time. Sixth factor is availability of government aid. This aid can be in four type including no aid, only seed aid, seed and fertilizer aid, seed, fertilizer and replanting cost aid. Seventh factor is replanting cost. This cost is divided into two based on way of replanting. First level is IDR 7,500,000, which is cost for replanting if replanting uses manual way. Second level is IDR 15,000,000, which is cost for replanting if it uses mechanization in replanting process. This cost is for 1-hectare rubber plantation. The last factor is replanting training. This factor is used to describe skill of rubber smallholder to replant their land. There are two factor levels, which are ever get replanting training and never get replanting training. Table below summarizes these factors.

Factors and factor levels that influence decision to give fertilizer and decision to replanting by rubber smallholder

No	Factors	Factor Levels
Factor and Factor levels for Decision to give fertilizer		
1	Latex Price	IDR 5000 (1), IDR 7500 (2), IDR 10,000 (3), IDR 12,500 (4)
2	Fertilizer price	IDR 120,000 (1), IDR 300,000 (2)
3	Availability of fertilizer	Available in certain time (1), Available all the time (2)
4	Impact of fertilizer	10% (1), 30% (2)
Factor and Factor level for decision to replant their land		
1	Latex Price	IDR 5000 (1), IDR 7500 (2), IDR 10,000 (3), IDR 12,500 (4)
2	Palm oil price	IDR 1000 (1), IDR 2000 (2), IDR 3,000 (3), IDR 4,000 (4)
3	Rubber wood price	No price (1), IDR 2,500,000 (2), IDR 5,000,000 (3), IDR 7,500,000(4)
4	Rubber seed price	IDR 7000 (1), IDR 13,000 (2)
5	Availability of rubber seed	Available in certain time (1), Available all the time (2)
6	Availability of government aid	No government aid (1), Seed aid only (2), Seed and fertilizer aid (3), Seed, fertilizer and replanting cost aid (4)
7	Replanting cost	IDR 7,500,000 (1), IDR 15,000,000 (2)
8	Replanting training	Ever get replanting training (1), never get replanting training (2)

Factors Levels for Decision of Latex Price at Village Level

This decision influence income of rubber smallholders and village suppliers, which in turn influence social sustainability of these key players. Village supplier observes certain factors before deciding daily latex price. First, village supplier use latex price at primary processor as basis to calculate latex price for rubber smallholder, then another factors are considered including quality of latex, quantity of latex, transportation cost, number of rivals, distance to plantation and total of profit that want to gain.

To define factors levels for every influential factor, current condition of Indonesia rubber supply network use as a basis. First is latex price at primary processor. Everyday primary processor will announce latex price for their supplier, this can be different between primary processor. This price is determined based on international rubber price such as SICOM (Singapore Commodity price). Factor level is average latex price at primary processor. Current latex price at primary processor is around IDR 12.900-13.200. Hence, IDR 13.000 is decided as first level for this factor. Other factor levels are IDR 18,000, IDR 23,000 and IDR 28,000.

In term of quality, current practice indicates that quality is observed visually by predicting dry rubber content (DRC) of latex. This standard is used by primary processor to measure quality of latex. Currently, DRC of latex from different districts in North Sumatera Province can be categorized into four including 40-45%, 46-50%, 51-55% and 56-60%. In term of quantity, village supplier is collected amount of latex from smallholder, which only own area less than 5 Ha. Usually, rubber smallholder produce amount of latex between 1-600 Kg per week. Hence, factor levels are categorized into 0-150 Kg, 151-300 Kg, 301-450 Kg and 451-600 Kg.

Village supplier use motorcycle to collect latex from smallholder's plantation. Transportation cost is calculated based on operational of motorcycle per day. Hence, factor level is determined using different price of gasoline in Indonesia. There are four factor levels, which are IDR 13,500, IDR 18,000, IDR 20,800 and IDR 21,700. Furthermore, distance to plantation will influence transportation cost. Village supplier only cover village area, some village supplier is able to collect latex in radius 20 Km, some village supplier even have covering area less than 10 Km. Factor levels for this factor are categorized into four levels including 0-5Km, 6-10 Km, 11-15 Km and 16-20 Km.

Number of rival will influence latex price at village level. If many village supplier exist in one village, they will try to compete each other in getting latex supply from rubber smallholder. Usually there are 2-10 village suppliers in every village depending on total area of rubber plantation in that village. Hence, factor levels for this factor are 0-5 village suppliers and 6-10 village suppliers. The last factor is profit wanted to gain. In qualitative phase, village supplier explained that they usually take profit around IDR 50-600 per kg-wet latex. Hence, levels of this factor are categorized as IDR 0-150, IDR 150-300, IDR 300-450 and IDR 450-600. Table below summarizes these factors.

Factors and Levels that Influence Decision of Village Supplier in Determining Latex Price

No	Factors	Levels
1	Latex Price at Primary Processor	IDR 13,000 (1), IDR 18,000 (2), IDR 23,000 (3), IDR 28,000 (4)
2	Transportation cost	IDR 13,500 (1), IDR 18,000 (2), IDR 20,800 (3), IDR 21,700 (4)
3	Weight of Latex	0-150 Kg (1), 150-300 Kg (2), 300-450 Kg (3), 450-600 Kg (4)
4	Distance to plantation	0-5 Km (1), 6-10 Km (2), 11-15 Km (3), 16-20 Km
5	Dry rubber content (Visually observed)	40-45% (1), 46-50% (2), 51-55% (3), 56-60% (4)
6	Number of rivals	0-5 Village Supplier (1) and 6-10 Village supplier
7	Profit taking	IDR 0-150 (1), IDR 151-300 (2), IDR 301-450 (3), IDR 451-600 (4)

Factors Levels for Decision of Latex Price at District Level

Similar with village supplier, at district stage, determining latex price is important decision. This price influences latex price at village level. Hence, this price influences income of key players at village level, which are rubber smallholders and village suppliers. To determine this price, district supplier is influenced by several factors including latex price at primary processor, transportation cost, quality of latex, quantity of latex, distance from village to primary processor, availability of latex in that village, number of rivals and profit taking. These influential factors can be varied in the fields depend on condition of district and village.

To determine factor levels for every influential factor, current condition of these factors in North Sumatera supply network is used as basis. Furthermore, factor levels are designed to produce different effect. Sometimes low difference between levels could not produce different effect. Hence, difference of factor levels should be able to trigger different response from respondent. Currently, latex price at primary processor is around IDR 12.700 – 13.200. Hence, IDR 13.000 is used as basis to determine factors level for latex price at primary processor. To trigger different responses from respondent, interval of IDR 5.000 is established. As the result, factors levels for latex price at primary processor are IDR13.000, IDR 18.000, IDR 23.000 and IDR 28.000.

District supplier use truck with capacity 5-10 Ton for sending latex to primary processor. Majority of district suppliers rent truck from other company. Hence, transportation cost is calculated based on cost of truck rental, labour cost and gasoline cost. Four factor levels for transportation cost are IDR 1.000.000, IDR 1.500.000, IDR 2.000.000 and IDR 2.500.000. For quality of latex, currently some districts in North Sumatera Province produce difference range quality of latex. Quality of latex is valued based on Dry rubber content. Districts in North Sumatera province produce latex with quality range from 40-60% (DRC). Hence, factor levels for quality of latex are 40-45%, 46-50%, 51-55% and 56-60%.

Quantity of latex are determined based on quantity of latex is offered by village supplier to district supplier. Quantity could be varied from 500 Kg to more than 3000 Kg. Factor levels are determined in this range. They are less than 500 Kg, 500-1500 Kg, 1500-3000 Kg and More than 3000 Kg. Qualitative study indicates that district supplier always sends latex to nearest primary processor except nearest primary processor that no longer accept latex due to out of capacity. Current condition in North Sumatera province, distance from rubber plantation in different districts to primary processor could be range from 10 Km – 350 Km. Hence, factor levels for this influential factor are 0-100 Km, 100-200 Km, 200-300 Km and more than 300 Km.

Availability of latex from one village depends on productive area of rubber plantation. Hence, this could be varied from 5000 – 18000 Kg. Factor levels are determined within this range. They are less than 5000 Kg, 5000-10.000 Kg, 10.000-15.000 Kg and More than 15.000 Kg. Number of rival is important for determining price. Many rivals operate at same district will reduce probability to get latex supply from village supplier due to competition with other district supplier. Currently, there are 1-10 district suppliers for one districts or operating in one district. Factors levels for this factor are 1-5 district suppliers and 6-10 district suppliers. Last factor is considered in determining latex price is profit taking. If district supplier wants to gain high profit, they will reduce latex price at district level or low profit taking will increase latex price at district level. Currently in North Sumatera province, district supplier takes profit between IDR 50 – 1000 per Kg latex. As the result factor levels for this influential factor are IDR 0- 250, IDR 251-500, IDR 501-750 and IDR 751-1000. Table below summarizes factor and factor levels for district supplier.

Factors and Factor Levels that Influence Decision of District Supplier in Determining Latex Price

No	Factors	Factor Levels
1	Latex price at primary processor	IDR 13.000 (1), IDR 18.000 (2), 23.000 (3) and IDR 28.000 (4)
2	Transportation cost	IDR 1.000.000 (1), IDR 1.500.000 (2), IDR 2.000.000 (3) and IDR 2.500.000 (4)
3	Weight of latex	Less than 500 Kg (1), 500-1500 Kg (2), 1500-3000 Kg (3) and more than 3000 Kg
4	Distance from plantation to primary processor	0-100 Km (1), 100-200 Km (2), 200-300 Km (3) and more than 300 km (4)
5	Dry rubber content	40-45% (1), 46-50% (2), 51-55% (3), 56-60% (4)
6	Number of rivals	0-5 Village Supplier (1) and 6-10 Village supplier
7	Availability of latex	Less than 5000 Kg (1), 5000-10000 Kg (2), 10.000 – 15.000 Kg (3) and more than 15.000 Kg
8	Profit taking	IDR 0-250 (1), IDR 250-500 (2), IDR 500-750 (3), IDR 750 – 1000 (4)

B.1.2 Designing Discrete Choice Experiment

Discrete choice experiment was designed by combining factors levels into several hypothetical condition. The experiment has been designed using orthogonal plan. The experiment using orthogonal plan will ensure the main effects of factors could be captured. To protect the main effects and two way linier interaction between factor levels, the hypothetical conditions resulted by combining factor levels using orthogonal plan were folded over. This step has been resulted 16 hypothetical conditions for decision to give fertilizer and 32 hypothetical conditions for decision to replant and decision to determine latex price for village supplier and district supplier.

B.1.3 Validation of Discrete Choice Questionnaire

Discrete choice questionnaire was validated by expert panel. The members of expert panel evaluated the factors levels in discrete choice questionnaire to ensure the experiment could trigger different responses from participants. Hence, the effect of influential factors into decision could be observed. Furthermore, before the real survey was run, preliminary survey was conducted using small participants to observed how the participants' response to the experiment. Feedback from expert panel was used to revise questionnaires while feedback from preliminary survey was used to inform the real survey.

B.2 Discrete Choice Questionnaire for Rubber Smallholders

This questionnaire consist of two parts which are: socio economic profile and discrete choice experiment. Socio economic profile will capture general information and economic characteristics of rubber smallholders. Discrete choice experiment is conducted to observe responses and decisions about giving fertilezer and replanting from rubber smallholders.

You are required to fill this questionnaire based on your experience and knowledge. Your responses reflect your real decisions if you face similar circumtances in real life. We also expect that you give the responses honestly without any worries.

A. Socio Economic Profile

Name	
Age	
Statue	
Education Level	
Square of Rubber Plantation	
Legality of Land for rubber Plantation	
History of your land	
How many family members are under your responsibility	
Income from rubber plantation	
Any other source of income	
Side Job	

B. Discrete Choice Experiment

In this part, you will be faced series of choices which are formed from combining factors that are expected to influence you in making decisions. These factors have been appeared from qualitative study which has been conducted before this experiment. There are two important decisions making by rubber smallholders that need to investigate further including:

- Decision to give fertilizer to their rubber plantation. This decision is important to investigate because this activities will influence productivity of rubber plantation.
- Decision to replant their land. This decision is important to investigate because this activities will influence sustainable rubber supply.

B.1. Decision to give fertilizer

Qualitative study has delivered factors which influence rubber smallholders in making decision to give fertilizer for their rubber plantations. There are:

- Fertilizer price, fertilizer price appear in table below is fertilizer price for 50 Kg. This factor is categorized into two levels which are 120.000 (IDR) and 300.000 (IDR).
- Latex price, latex price appear in table below is a price for 1 Kg wet Latex. This factor is categorized into four levels which are 5000 (IDR), 7500 (IDR), 10,000 (IDR) and 12,500 (IDR)
- Availability of fertilizer is supply level of fertilizer in your area by fertilizer supplier. This factor is categorized into two which are available in certain time and available all the time
- Impact of fertilizer is related with increasing of latex production if fertilizer is applied to rubber plantation compared with rubber plantation without fertilizer treatment. This factor is categorized into two including increasing of latex production by 10% and increasing latex production by 30%

You are expected to take decision in every set of choice by giving word “YES” for “I will give fertilizer to my plantation” and “NO” for “I will not give fertilizer to my plantation”.

Please giving your answer “Yes” or “NO” in answer column

Set	Fertilizer Price (in IDR)	Latex Price (in IDR)	Availability of Fertilizer	Impact of fertilizer (%)	Decision
1	120,000	7,500	available all the time	10	
2	120,000	10,000	available in certain time	30	
3	120,000	5,000	available in certain time	10	
4	300,000	7,500	available in certain time	30	

5	300,000	5,000	available all the time	30	
6	300,000	10,000	available all the time	10	
7	300,000	12,500	available in certain time	10	
8	120,000	12,500	available all the time	30	

(Block 1)

Please giving your answer "Yes" or "NO" in answer column

Set	Fertilizer Price (in IDR)	Latex Price (in IDR)	Availability of Fertilizer	Impact of fertilizer (%)	Decision
1	300,000	10,000	available in certain time	30	
2	300,000	7,500	available all the time	10	
3	300,000	12,500	available all the time	30	
4	120,000	10,000	available all the time	10	
5	120,000	12,500	available in certain time	10	
6	120,000	7,500	available in certain time	30	
7	120,000	5,000	available all the time	30	
8	300,000	5,000	available in certain time	10	

(Block 2)

B.2. Decision in Replanting Rubber Plantation

This part of questionnaire are expected your decision about replanting your land. When you fill this part of questionnaire, Your land is assumed that are in unproductive stage (25-30 Year age of your rubber tree). You are assumed at the moment when it needs to decide whether replant your plantation or not. The decision in this part is influenced by some factors. Qualitative study has resulted factors that influence rubber smallholders in choosing whether replant the plantation or not. The factors are:

- Latex price, latex price appear in table below is a price for 1 Kg wet Latex. This factor is categorized into four levels which are 5000 (IDR), 7500 (IDR), 10,000 (IDR) and 12,500 (IDR)

- Palm oil price, palm oil price appear in table below is a price for 1 Kg palm fruit. This factor is categorized into four levels which are 1000 (IDR), 2000 (IDR), 3000 (IDR) and 4000 (IDR)
- Price of rubber wood, this is a price for rubber wood if rubber smallholder decide to replant, then rubber wood is got from old rubber trees which are cut during replanting. The price is for wood from 1 Ha rubber plantation. Approximately, from 1 Ha, we can get around 300-400 bar of rubber wood. This factor is categorized into four levels which are 0 (rubber wood can not be sold), 2,500,000 (IDR), 5,000,000 (IDR) and 7,500,000 (IDR)
- Seed Price, seed price appear in table below is a price for 1 seed (with age 7 month – 1 year). This factor is categorized into two levels which are 7,000 (IDR) and 13,000 (IDR).
- Availability of seeds, this factor describe about the availability of standard seeds in replanting area. this factor is categorized into two levels including total seeds meet demand and total seeds do not meet demand
- Availability of government aid, this factor relates with government policy to give rubber smallholders aid for replanting their land. This factor is categorized into no aid, seeds aid, seeds and fertilizers aid and seeds, fertilizers and replanting cost aid.
- Replanting cost, this factors relates with cost that have to prepare by smallholders for replanting. This factor is categorized into two levels which are replanting cost without mechanization, 7,500,000/ Ha and replanting cost with mechanization 15,000,000/Ha
- Training for replanting, this factor relates with availability of training that has been received by rubber smallholders. This factor is categorized into two levels which are rubber smallholder has been got training and rubber smallholder has been not got training.

You are expected to take decision in every set of choice by giving word "YES" for "I will replant my plantation" and "NO" for "I will not replant my plantation".

Please giving your answer "Yes" or "NO" in answer column

Set	Latex Price (IDR)	Palm Fruit Price (IDR)	Rubber Wood Price/Ha (IDR)	Seed Price (IDR)	Avilability of Seeds	Availability of Government Aid	Replanting Cost	Getting Training for Replanting	Answer
1	5,000	4,000	2,500,000	7,000	Meet Demand	seeds, fertilizers and replanting cost aid	7,500,000	Ever	
2	5,000	4,000	5,000,000	13,000	Meet Demand	Seeds and fertilizers aid	7,500,000	Never	
3	7,500	4,000	7,500,000	13,000	Meet Demand	No aid	15,000,000	Ever	
4	12,500	1,000	0	13,000	Meet Demand	Seeds and fertilizers aid	15,000,000	Never	
5	7,500	1,000	2,500,000	7,000	Do not meet demand	Seeds and fertilizers aid	15,000,000	Ever	
6	12,500	4,000	5,000,000	7,000	Do not meet demand	No aid	15,000,000	Never	
7	7,500	1,000	5,000,000	13,000	Do not meet demand	seeds, fertilizers and replanting cost aid	15,000,000	Never	
8	7,500	3,000	5,000,000	13,000	Do not meet demand	Seeds and fertilizers aid	7,500,000	Ever	

(Block 1)

Please giving your answer "Yes" or "NO" in answer column

Set	Latex Price (IDR)	Palm Fruit Price (IDR)	Rubber Wood Price/Ha (IDR)	Seed Price (IDR)	Avilability of Seeds	Availability of Government Aid	Replanting Cost	Getting Training for Replanting	Answer
1	10000	3000	2500000	13000	Meet Demand	Seeds aid	15000000	Never	
2	12500	2000	5000000	7000	Do not meet demand	Seeds aid	7500000	Ever	
3	7500	2000	7500000	13000	Meet Demand	Seeds aid	7500000	Never	
4	12500	3000	0	13000	Meet Demand	seeds, fertilizers and replanting cost aid	7500000	Ever	
5	5000	1000	0	7000	Do not meet demand	No aid	7500000	Never	
6	7500	4000	0	7000	Meet Demand	Seeds aid	15000000	Never	
7	10000	4000	0	13000	Do not meet demand	seeds, fertilizers and replanting cost aid	7500000	Never	
8	5000	2000	5000000	13000	Meet Demand	seeds, fertilizers and replanting cost aid	15000000	Ever	

(Block 2)

Please giving your answer “Yes” or “NO” in answer column

Set	Latex Price (IDR)	Palm Fruit Price (IDR)	Rubber Wood Price/Ha (IDR)	Seed Price (IDR)	Avilability of Seeds	Availability of Government Aid	Replanting Cost	Getting Training for Replanting	Answer
1	5,000	3,000	7,500,000	13,000	Do not meet demand	No aid	15,000,000	Never	
2	12,500	2,000	2,500,000	13,000	Do not meet demand	No aid	7,500,000	Never	
3	10,000	3,000	5,000,000	7,000	Meet Demand	No aid	15,000,000	Ever	
4	5,000	3,000	0	7,000	Do not meet demand	Seeds aid	15,000,000	Ever	
5	5,000	2,000	2,500,000	7,000	Meet Demand	Seeds and fertilizers aid	15,000,000	Never	
6	10,000	2,000	7,500,000	7,000	Do not meet demand	seeds, fertilizers and replanting cost aid	15,000,000	Never	
7	12,500	3,000	7,500,000	7,000	Meet Demand	Seeds and fertilizers aid	7,500,000	Never	
8	10,000	1,000	2,500,000	13,000	Meet Demand	No aid	7,500,000	Ever	

(Block 3)

Please giving your answer "Yes" or "NO" in answer column

Set	Latex Price (IDR)	Palm Fruit Price (IDR)	Rubber Wood Price/Ha (IDR)	Seed Price (IDR)	Avilability of Seeds	Availability of Government Aid	Replanting Cost	Getting Training for Replanting	Answer
1	10,000	1,000	5,000,000	7,000	Meet Demand	Seeds aid	7500000	Never	
2	5,000	1,000	7,500,000	13,000	Do not meet demand	Seeds aid	7500000	Ever	
3	10,000	4,000	7,500,000	7,000	Do not meet demand	Seeds and fertilizers aid	7500000	Ever	
4	7,500	3,000	2,500,000	7,000	Do not meet demand	seeds, fertilizers and replanting cost aid	7500000	Never	
5	10,000	2,000	0	13,000	Do not meet demand	Seeds and fertilizers aid	15000000	Ever	
6	12,500	4,000	2,500,000	13,000	Do not meet demand	Seeds aid	15000000	Ever	
7	7,500	2,000	0	7,000	Meet Demand	No aid	7500000	Ever	
8	12,500	1,000	7,500,000	7,000	Meet Demand	seeds, fertilizers and replanting cost aid	15000000	Ever	

(Block 4)

B.3 Discrete Choice Questionnaire for Village Suppliers

This questionnaire consist of two parts which are: socio economic profile and discrete choice experiment. Socio economic profile will capture general information and economic characteristics of village collectors. Discrete choice experiment is conducted to observe responses and decisions about determining price of latex at village level.

You are required to fill this questionnaire based on your experience and knowledge. Your responses reflect your real decisions if you face similar circumtances in real life. We also expect that you give the responses honestly without any worries.

C. Socio Economic Profile

Name	
Age	
Statue	
Education Level	
Wide range of buying latex	
Legality of vehicle for supplying latex	
Amount of latex is supplied per week	
How many family members are under your responsibility	
Income from rubber plantation	
Any other source of income	
Side Job	

D. Discrete Choice Experiment

In this part, you will be faced series of choices which are formed from combining factors that are expected to influence you in making decisions. These factors have been appeared from qualitative study which has been conducted before this experiment. There are one important decisions making by village collectors that need to investigate further:

- Decision to determine a price for 1 kg wet latex at village level or at smallholders level

B.1. Decision to Determine Price at Village Level

Qualitative study has delivered factors which influence village collectors in making decision to determine a price for 1 kg wet latex at village level. There are:

- Dry Rubber Price at primary processor, the price appear at table below is a price for 1 Kg dry latex which determined by primary processor. This price will change everyday following rubber price at international level. This factor is categorized into four levels which are 13,000 (IDR), 18,000 (IDR), 23,000 (IDR) and 28,000 (IDR).
- Transportation cost, this cost is determined based on consumption of gasoline for motorcycle per day. The cost will change following the fluctuation of gasoline price in Indonesia. This factor is categorized into four levels 13,500 (IDR), 18,000 (IDR), 20,700 (IDR) and 21,700 (IDR).
- Weight of wet latex are offered by smallholder, this factor is categorized into four levels which are, 0-150Kg, 151-300 Kg, 301-450 Kg and 451- 600 Kg.
- Distance from village collector's location to smallholder's location, this factor is categorized into four levels including 0-5Km, 6-10 Km, 11-15 Km and 16-20 Km
- Dry rubber content, this is prediction of dry rubber content by village collectors using observation to smallholder's latex. This factor is categorized into four levels which are 40-45%, 46-50%, 51-55% and 56-60%.
- Number of rivals, this is a total of village collectors who operate in same area or same village. This factor is categorized into two levels which are 0-5 village collectors and 5-10 village collectors.
- Option for taking profit, this is a price gap per Kg wet latex which is profit taken by village collector. This option is categorized into four levels which are 0-150 /Kg wet latex (IDR), 151-300/Kg wet latex (IDR), 301-450/Kg wet Latex (IDR) and 451-600/Kg wet latex (IDR).

You are expected to take decision in every set of choice by giving word "YES" for "I agree with the option" and "NO" for "I do not agree with the option".

Please giving your answer "Yes" or "NO" in answer column

Set	Dry Rubber Price at Primary Processor (/Kg)	Transportation Cost (IDR)	Weight of wet latex (Kg)	Distance (Km)	Dry Rubber Content (%)	Total of rivals (People)	Option for Profit (IDR)	Answer
1	13000	18000	0-150 Kg	6-10 Km	56-60%	5-10	Rp151- Rp 300	
2	23000	20700	451-600 Kg	6-10 Km	40-45%	5-10	0-Rp 150	
3	28000	18000	151-300 Kg	11-15 Km	56-60%	5-10	0-Rp 150	
4	28000	21900	0-150 Kg	6-10 Km	40-45%	0-5	Rp 301-Rp. 450	
5	23000	18000	301-450 Kg	16-20 Km	40-45%	5-10	Rp 451 – Rp 600	
6	23000	13500	0-150 Kg	11-15 Km	51-55%	5-10	0-Rp 150	
7	18000	13500	151-300 Kg	6-10 Km	51-55%	5-10	Rp151- Rp 300	
8	13000	21900	451-600 Kg	11-15 Km	46-50%	5-10	Rp151- Rp 300	

(Block 1)

Please giving your answer “Yes” or “NO” in answer column

Set	Dry Rubber Price at Primary Processor (/Kg)	Transportation Cost (IDR)	Weight of wet latex (Kg)	Distance (Km)	Dry Rubber Content (%)	Total of rivals (People)	Option for Profit (IDR)	Answer
1	18000	18000	451-600 Kg	0-5Km	40-45%	5-10	Rp 301-Rp. 450	
2	18000	21900	0-150 Kg	16-20 Km	51-55%	5-10	Rp 301-Rp. 450	
3	28000	20700	0-150 Kg	0-5Km	56-60%	5-10	Rp 451 – Rp 600	
4	18000	20700	0-150 Kg	11-15 Km	46-50%	0-5	Rp 451 – Rp 600	
5	28000	13500	451-600 Kg	16-20 Km	46-50%	5-10	Rp 451 – Rp 600	
6	13000	21900	151-300 Kg	11-15 Km	40-45%	0-5	Rp 451 – Rp 600	
7	13000	18000	301-450 Kg	6-10 Km	51-55%	0-5	Rp 451 – Rp 600	
8	13000	20700	151-300 Kg	16-20 Km	56-60%	5-10	Rp 301-Rp. 450	

(Block 2)

Please giving your answer "Yes" or "NO" in answer column

Set	Dry Rubber Price at Primary Processor (/Kg)	Transportation Cost (IDR)	Weight of wet latex (Kg)	Distance (Km)	Dry Rubber Content (%)	Total of rivals (People)	Option for Profit (IDR)	Answer
1	23000	21900	451-600 Kg	0-5Km	56-60%	0-5	Rp151- Rp 300	
2	28000	13500	151-300 Kg	16-20 Km	40-45%	0-5	Rp151- Rp 300	
3	28000	21900	301-450 Kg	6-10 Km	46-50%	5-10	0-Rp 150	
4	13000	13500	0-150 Kg	0-5Km	40-45%	0-5	0-Rp 150	
5	18000	21900	301-450 Kg	16-20 Km	56-60%	0-5	0-Rp 150	
6	23000	18000	0-150 Kg	16-20 Km	46-50%	0-5	Rp151- Rp 300	
7	23000	21900	151-300 Kg	0-5Km	51-55%	5-10	Rp 451 – Rp 600	
8	13000	13500	301-450 Kg	0-5Km	46-50%	5-10	Rp 301-Rp. 450	

(Block 3)

Please giving your answer “Yes” or “NO” in answer column

Set	Dry Rubber Price at Primary Processor (/Kg)	Transportation Cost (IDR)	Weight of wet latex (Kg)	Distance (Km)	Dry Rubber Content (%)	Total of rivals (People)	Option for Profit (IDR)	Answer
1	23000	13500	301-450 Kg	11-15 Km	56-60%	0-5	Rp 301-Rp. 450	
2	28000	20700	301-450 Kg	0-5Km	51-55%	0-5	Rp151- Rp 300	
3	23000	20700	151-300 Kg	6-10 Km	46-50%	0-5	Rp 301-Rp. 450	
4	18000	20700	301-450 Kg	11-15 Km	40-45%	5-10	Rp151- Rp 300	
5	18000	18000	151-300 Kg	0-5Km	46-50%	0-5	0-Rp 150	
6	13000	20700	451-600 Kg	16-20 Km	51-55%	0-5	0-Rp 150	
7	18000	13500	451-600 Kg	6-10 Km	56-60%	0-5	Rp 451 – Rp 600	
8	28000	18000	451-600 Kg	11-15 Km	51-55%	0-5	Rp 301-Rp. 450	

(Block 4)

B.4 Discrete Choice Questionnaire for District Suppliers

This questionnaire consist of two parts which are: socio economic profile and discrete choice experiment. Socio economic profile will capture general information and economic characteristics of district suppliers. Discrete choice experiment is conducted to observe responses and decisions about determining price of latex at district level.

You are required to fill this questionnaire based on your experience and knowledge. Your responses reflect your real decisions if you face similar circumtances in real life. We also expect that you give the responses honestly without any worries.

E. Socio Economic Profile

Name	
Age	
Statue	
Education Level	
Wide range of buying latex	
Legality of vehicle for supplying latex	
Amount of latex is supplied per week	
How many family members are under your responsibility	
Income from rubber plantation	
Any other source of income	
Side Job	

F. Discrete Choice Experiment

In this part, you will be faced series of choices which are formed from combining factors that are expected to influence you in making decisions. These factors have been appeared from qualitative study which has been conducted before this experiment. There are one important decisions making by district suppliers that need to investigate further:

- Decision to determine a price for 1 kg wet latex at district level

B.1. Decision to Determine Price at District Level

Qualitative study has delivered factors which influence district suppliers in making decision to determine a price for 1 kg wet latex at district level. There are:

- Dry Rubber Price at primary processor, the price appear at table below is a price for 1 Kg dry latex which determined by primary processor. This price will change everyday following rubber price at international level. This factor is categorized into four levels which are 13,000 (IDR), 18,000 (IDR), 23,000 (IDR) and 28,000 (IDR).
- Transportation cost, this cost is used for delivering latex from village to primary processor. The cost consists of rent cost, gasoline cost and labor cost. This factor is categorized into four levels 1,000,000 (IDR), 1,500,000 (IDR), 2,000,000 (IDR) and 2,500,000 (IDR).
- Weight of wet latex are offered by village collector, this factor is categorized into four levels which are, 500Kg, 500-1500 Kg, 1501-3000 Kg and more than 3000 Kg.
- Distance from village collector's location to primary processor's location, this factor is categorized into four levels including 0-100Km, 101-200 Km, 201-300 Km and more than 300 Km
- Dry rubber content, this is prediction of dry rubber content by district suppliers using observation to village collector's latex. This factor is categorized into four levels which are 40-45%, 46-50%, 51-55% and 56-60%.
- Number of rivals, this is a total of village collectors who operate in same area or same village. This factor is categorized into two levels which are 0-5 district suppliers and 5-10 district suppliers.
- Availability of latex from village, this factor describes total of latex from one village at the moment when district supplier comes to that village. This factor is categorized into four levels which are 0-5000 Kg, 5001-10,000 Kg, 10,001-15,000 Kg and More than 15,000 Kg.
- Option for taking profit, this is a price gap per Kg wet latex which is profit taken by district supplier. This option is categorized into four levels which are 0-250/Kg wet latex (IDR), 251-500/Kg wet Latex (IDR), 501-750/Kg wet latex (IDR) and 751-1000 /Kg wet latex (IDR) .

You are expected to take decision in every set of choice by giving word "YES" for "I agree with the option" and "NO" for "I do not agree with the option".

Please giving your answer "Yes" or "NO" in answer column

Set	Dry Rubber Price at Primary Processor (IDR)	Transportation cost (IDR)	Dry Rubber Content (%)	Weight of Wet Latex (Ton)	Distance from Village to primary processor (Kg)	Total of rivals (People)	Availability of latex from village (Ton)	Option for Profit (/Kg)	Answer
1	23000	1500000	40-45%	More than 3 Ton	0-100Km	0-5	More than 15 ton	Rp251- Rp 500	
2	18000	1500000	56-60%	1,5 Ton – 3 Ton	101-200 Km	5-10	0-5 ton	Rp251- Rp 500	
3	18000	2000000	46-50%	1,5 Ton – 3 Ton	0-100Km	5-10	More than 15 ton	0-Rp 250	
4	23000	1500000	46-50%	500 Kg – 1 ,5 Ton	101-200 Km	0-5	5-10 ton	4	
5	23000	2500000	40-45%	1,5 Ton – 3 Ton	201-300 Km	5-10	0-5 ton	Rp 501-Rp. 750	
6	28000	2000000	56-60%	Less than 500 Kg	More than 300 Km	0-5	0-5 ton	4	
7	28000	2000000	51-55%	1,5 Ton – 3 Ton	201-300 Km	0-5	10-15 ton	Rp251- Rp 500	
8	13000	1500000	56-60%	More than Ton	201-300 Km	2	10-15 ton	0-Rp 250	

(Block 1)

Please giving your answer “Yes” or “NO” in answer column

Set	Dry Rubber Price at Primary Processor (IDR)	Transportation cost (IDR)	Dry Rubber Content (%)	Weight of Wet Latex (Ton)	Distance from Village to primary processor (Kg)	Total of rivals (People)	Availability of latex from village (Ton)	Option for Profit (/Kg)	Answer
1	23000	1000000	51-55%	1,5 Ton – 3 Ton	More than 300 Km	5-10	More than 15 ton	Rp 751 – Rp 1000	
2	18000	2000000	40-45%	Less than 500 Kg	101-200 Km	5-10	5-10 ton	Rp 501-Rp. 750	
3	28000	1000000	56-60%	500 Kg – 1 ,5 Ton	101-200 Km	5-10	More than 15 ton	0-Rp 250	
4	13000	2500000	51-55%	Less than 500 Kg	101-200 Km	0-5	More than 15 ton	Rp251- Rp 500	
5	18000	1000000	46-50%	More than 3 Ton	201-300 Km	0-5	0-5 ton	Rp 751 – Rp 1000	
6	13000	2000000	40-45%	500 Kg – 1 ,5 Ton	201-300 Km	5-10	More than 15 ton	Rp 751 – Rp 1000	
7	13000	2500000	56-60%	1,5 Ton – 3 Ton	0-100Km	0-5	5-10 ton	Rp 751 – Rp 1000	
8	23000	2000000	56-60%	500 Kg – 1 ,5 Ton	0-100Km	0-5	10-15 ton	Rp 501-Rp. 750	

(Block 2)

Please giving your answer "Yes" or "NO" in answer column

Set	Dry Rubber Price at Primary Processor (IDR)	Transportation cost (IDR)	Dry Rubber Content (%)	Weight of Wet Latex (Ton)	Distance from Village to primary processor (Kg)	Total of rivals (People)	Availability of latex from village (Ton)	Option for Profit (/Kg)	Answer
1	13000	1500000	51-55%	500 Kg – 1 ,5 Ton	More than 300 Km	5-10	0-5 ton	Rp 501-Rp. 750	
2	18000	2500000	56-60%	More than 3 Ton	More than 300 Km	0-5	More than 15 ton	Rp 501-Rp. 750	
3	18000	1000000	40-45%	500 Kg – 1 ,5 Ton	More than 300 Km	0-5	10-15 ton	Rp251- Rp 500	
4	28000	1000000	51-55%	More than 3 Ton	0-100Km	5-10	5-10 ton	Rp 501-Rp. 750	
5	18000	2500000	51-55%	500 Kg – 1 ,5 Ton	201-300 Km	0-5	5-10 ton	0-Rp 250	
6	28000	2500000	40-45%	More than 3 Ton	101-200 Km	5-10	10-15 ton	Rp 751 – Rp 1000	
7	28000	1500000	46-50%	Less than 500 Kg	201-300 Km	0-5	More than 15 ton	Rp 501-Rp. 750	
8	28000	1500000	40-45%	1,5 Ton – 3 Ton	More than 300 Km	0-5	5-10 ton	0-Rp 250	

(Block 3)

Please giving your answer "Yes" or "NO" in answer column

Set	Dry Rubber Price at Primary Processor (IDR)	Transportation cost (IDR)	Dry Rubber Content (%)	Weight of Wet Latex (Ton)	Distance from Village to primary processor (Kg)	Total of rivals (People)	Availability of latex from village (Ton)	Option for Profit (/Kg)	Answer
1	18000	1500000	51-55%	Less than 500 Kg	0-100Km	5-10	10-15 ton	Rp 751 – Rp 1000	
2	13000	1000000	46-50%	1,5 Ton – 3 Ton	101-200 Km	0-5	10-15 ton	Rp 501-Rp. 750	
3	13000	2000000	46-50%	More than 3 Ton	More than 300 Km	5-10	5-10 ton	Rp251- Rp 500	
4	23000	1000000	56-60%	dibawah 500 Kg	201-300 Km	5-10	5-10 ton	Rp251- Rp 500	
5	23000	2000000	51-55%	More than 3 Ton	101-200 Km	0-5	0-5 ton	0-Rp 250	
6	13000	1000000	40-45%	Less than 500 Kg	0-100Km	0-5	0-5 ton	0-Rp 250	
7	23000	2500000	46-50%	Less than 500 Kg	More than 300 Km	5-10	10-15 ton	0-Rp 250	
8	28000	2500000	46-50%	500 Kg – 1 ,5 Ton	0-100Km	5-10	0-5 ton	Rp251- Rp 500	

(Block 4)

Appendix C Parameters of Simulation Models

C.1 Parameters of System Dynamics

Name of Parameters	Value
Rubbersmallholder_growthrate	0
rubberprice	1 (refer to IDR 5.000/Kg)
woodprice	3 (refer to IDR 5.000.000/Ha)
palmoil_price	1 (refer to IDR 1.000/Kg)
rubberseed_price	1 (refer to IDR 7.500/Kg)
availability_rubberseed	2 (refer to rubber seed is not available all the time)
availability_governmentaid	1 (refer to no government aid for replanting)
replanting_cost	1 (refer to IDR 7.500.000/Ha)
replantingtraining	2 (refer to never get replanting training)
Proportion_changingland	0.3
RateCH4	52.39 Kg CH4 e / Ha
Rate N2O	1.36 Kg CH4 e / Ha
AvgRubberTree	400
fertilizerDose	0.9 (refer to 0.9 gr/tree)
prodrate_phase1	800 Kg/year
prodrate_phase2	900 Kg/year
prodrate_phase3	1000 Kg/year
prodrate_phase4	1000 Kg/year
prodrate_phase5	900 Kg/year
prodrate_phase6	300 Kg/year
Stepper_performance	1 Ha/day
Carbon_absorbtion	4.65 ton CO2/year/Ha
CarbonStockImmature	18.90 Kg C/year
CarbonStockProductiveLand	87.74 Kg C/year/Ha
CarbonStockinLatex	0.8 C/Kg Latex
EmissionNPK	7.012 CO e/Kg NPK
Proportion_useHerbicide	0.4
Gluphosate	6.25 l/Ha
EmissionfromHerbicide	16 CO e/Kg Gluphosate

Avg_vilsup_capacity	52.000 Kg/year
Avg_dissup_capacity	468.000 Kg/year
Avg_trader_capacity	1.300.000 Kg/year

Function in System Dynamics

Name of Dynamic Variable and Stock	**Function**
Life cycle of plantation and land change	
New smallholders	Smallholder growth rate
Population Rubber Smallholders	d/dt = (new smallholders – reduction of rubber smallholders)
Reduction of rubber smallholders	Stop to be rubber smallholders
New Immature	New rubber plantation area + Total replanting
Immature Plantation	d/dt = (New immature – Enter phase 1)
Enter phase 1	Time < 6 ? Maturation rate 1 : Year 6
Plantation year 6-10	d/dt = (Enter phase 1 – Enter phase 2)
Enter phase 2	Time < 4 ? Maturation rate 2 : Year 10
Plantation year 10-15	d/dt = (Enter phase 2 – Enter phase 3)
Enter phase 3	Time < 5 ? Maturation rate 3 : Year 15
Plantation year 15-20	d/dt = (Enter phase 3 – Enter phase 4)
Enter phase 4	Time < 5 ? Maturation rate 4 : Year 20
Plantation year 20-25	d/dt = (Enter phase 4 – Enter phase 5)
Enter phase 5	Time < 5 ? Maturation rate 5 : Year 25
Plantation year 25-30	d/dt = (Enter Phase 5 – Enter phase 6)
Enter phase 6	Time < 5 ? Maturation rate 6 : Year 30
Non-productive plantation	d/dt = (Enter phase 6 – (Replanting by smallholders + Non replanting area)
Replanting by smallholders	Proportion to replant * Average land per smallholder
Non replanting area	Proportion not to replant * Average land per smallholder
Old plantation	d/dt= (Non replanting area – (land change + Replanting intervention)
Land change	Total switch area
Replanting intervention	Rate of replanting intervention
Rate of replanting intervention	Table of replanting intervention rate (time)

Total replanting	Replanting by smallholders + Replanting intervention
Total Productive Area	Plantation year 6-10 + Plantation year 10-15 + Plantation year 15-20 + Plantation year 20-25 + Plantation year 25-30 + Old Plantation
Smallholder with non-productive land	Immature Plantation/ Average land per smallholder
Proportion to switch crop	Table of switching crop rate (time)
Total switch area	Proportion to switch crop * (Old plantation – Replanting intervention)
Total rubber plantation area	Immature Plantation + Total productive area
Average land per smallholder	Total rubber plantation area / population rubber smallholders
Proportion to replant	Equation 4.2 (section 4.2.1)
Proportion not to replant	(1-Proportion to replant)
Year 1- Year 30	Delay material (X,1,0,0)
Latex Production	
Latex prod from phase 1	Prod rate phase 1 * Plantation year 6-10 * Proportion area covered by tapper
Latex prod from phase 2	Prod rate phase 2 * Plantation year 10-15 * Proportion area covered by tapper
Latex prod from phase 3	Prod rate phase 3 * Plantation year 15-20 * Proportion area covered by tapper
Latex prod from phase 4	Prod rate phase 4 * Plantation year 20-25 * Proportion area covered by tapper
Latex prod from phase 5	Prod rate phase 5 * Plantation year 25-30 * Proportion area covered by tapper
Latex prod from phase 6	Prod rate phase 6 * Old plantation * Proportion area covered by tapper
New Tapper	Tapper growth rate
Population of Tapper	d/dt = (New tapper – reduction of tapper)
Reduction of tapper	Changing profession
Tapper rate	Population of Tapper * Tapper performance
Productive area/tapper rate	Total productive area/tapper rate
Tapper growth rate	Productive area/tapper rate >1 ? Needs new tapper : 0
Changing profession	Productive area/tapper rate < 1 ? Reduce current tapper : 0
Needs new tapper	(Total productive area – tapper rate)/ tapper performance

Reduce current tapper	(tapper rate – total productive area)/ tapper performance
Proportion area covered by tapper	Productive area/tapper rate
Total latex production	Latex prod from phase 1 + Latex prod from phase 2 + Latex prod from phase 3 + Latex prod from phase 4 + Latex prod from phase 5 + Latex prod from phase 6
Lump production	Total latex production * Proportion to be lump
Slab production	Total latex production * Proportion to be slab
Sheet production	Total latex production * Proportion to be sheet
Proportion to give fertilizer	Equation 4.1 (section 4.2.1)
Total rubber tree	Proportion to give fertilizer * population rubber smallholders * average land per smallholders * Average rubber tree per hectare
Use of fertilizer	Total rubber tree * fertilizer dose
Use of herbicide	Proportion to use herbicide * Total rubber plantation area * Herbicide rate
Total emission from fertilizer	Emission rate from fertilizer * use of fertilizer
Total emission from herbicide	Emission rate from herbicide * use of herbicide
CH4 emission from replanting	Total Replanting * CH4 emission rate
N2O emission from replanting	Total Replanting * N2O emission rate
Carbon stock for productive plantation	Carbon stock rate for productive plantation * Total Productive Area
Carbon stock for immature plantation	Carbon stock rate for immature plantation * Immature plantation
Carbon stock in latex	Carbon stock rate in latex * latex production
Total carbon stock	Carbon stock for productive plantation + Carbon stock for immature plantation + Carbon stock in latex
Carbon sequestration	Carbon sequestration rate * Total productive area
Latex Distribution	
Latex collect by village supplier	Lump production + slab production + sheet production
Population of village supplier	d/dt = (new village supplier – reduction village supplier)
New village supplier	Village supplier growth rate
Reduction village supplier	Changing profession
Supply rate by village supplier	Population village supplier * village supplier avg capacity

Latex production/supply rate by village supplier	Total latex production / supply rate by village supplier
Village supplier growth rate	Total latex production / supply rate by village supplier > 1 ? Needs new village supplier : 0
Changing profession	Total latex production / supply rate by village supplier < 1 ? reduce current village suppliers : 0
Needs new village suppliers	(Total latex production – supply rate by village supplier)/ village supplier avg capacity
Reduce current village suppliers	(supply rate by village supplier – total latex production)/ village supplier avg capacity
Population of district supplier	d/dt = (new district supplier – reduction district supplier)
New district supplier	District supplier growth rate
Reduction district supplier	Changing profession
Supply rate by district supplier	Population district supplier * district supplier avg capacity
Latex production/supply rate by district supplier	Total latex production / supply rate by district supplier
District supplier growth rate	Total latex production / supply rate by district supplier > 1 ? Needs new district supplier : 0
Changing profession	Total latex production / supply rate by district supplier < 1 ? reduce current district suppliers : 0
Needs new district suppliers	(Total latex production – supply rate by district supplier)/ district supplier avg capacity
Reduce current district suppliers	(supply rate by district supplier – total latex production)/ district supplier avg capacity
Population of traders	d/dt = (new trader – reduction trader)
New trader	Village supplier growth rate
Reduction trader	Changing profession
Supply rate by trader	Population trader * trader avg capacity
Latex production/supply rate by traders	Total latex production / supply rate by trader
Trader growth rate	Total latex production / supply rate by trader > 1 ? Needs new trader : 0
Changing profession	Total latex production / supply rate by trader < 1 ? reduce current trader : 0
Needs new traders	(Total latex production – supply rate by trader)/ trader avg capacity
Reduce current traders	(supply rate by trader – total latex production)/ trader avg capacity

Primary processors demand	Total primary processors * Average capacity of primary processors
Utilization of primary processors	Total latex production / Primary processors demand

C.2 Parameters of Agent Based Simulation

Name of Parameters	Value
Warehouse capacity for rubber plantation	Uniform_discrete (500,700)
Area for rubber plantation	Uniform_discrete (1,10)
Production rate of latex for rubber plantation	Uniform_discrete (5,6) * Area
Warehouse_capacity for village supplier	Uniform_discrete (1500,2000)
Warehouse_capacity for district supplier	Uniform_discrete (10000,20000)
Warehouse_capacity for rubber trader	Uniform_discrete (100000,200000)

Population of agent in Simulation for Langkat District

Sub District	Latitude Reference	Longitude Reference	Population of smallholder in simulation	Population of village supplier in simulation	Population of district supplier in simulation	Population of smallholder in reality
Bahorok	98,11140	3,46897	320	32	4	3200
Salapian	98,28162	3,41964	428	43	4	4278
Seibingei	98,40791	3,39772	127	13	2	1273
Kuala	98,35026	3,45527	96	10	1	962
Selesai	98,39144	3,58132	71	7	0	714
Binjai	98,46008	3,62790	2	0	0	15
Stabat	98,46283	3,73201	3	0	0	25
Wampu	98,33928	3,67996	103	10	0	1026
Batangserangan	98,06199	3,65530	242	24	2	2418
Sawitseberang	98,18554	3,79228	70	7	0	700
Padangtualang	98,34203	3,87446	73	7	0	730
Hinai	98,40792	3,81967	8	1	0	78
Secanggang	98,54519	3,85254	5	0	0	45
Tanjungpura	98,47381	3,95389	0	0	0	1
Gebang	98,36948	3,97580	8	1	0	78
Babalan	98,33653	4,02784	12	1	0	123
Seilepan	98,14984	3,87172	180	18	3	1800
Brandanbarat	98,24593	4,03606	17	2	0	165

Besitang	98,05375	3,92651	147	15	3	1470
Pangkalansusu	98,13611	4,10727	15	2	0	150
Serapit	98,29315	3,55666	135	14	1	1352
Kutambaru	98,24373	3,33742	161	16	2	1612
Pematangjaya	98,15313	4,24417	25	3	0	254

Population of agent in Simulation for Deli Serdang District

Sub District	Latitude Reference	Longitude Reference	Population of smallholder in simulation	Population of village supplier in simulation	Population of district supplier in simulation	Population of smallholder in reality
STMHulu	98,64916	3,26691	146	15	2	1458
BangunPurba	98,75898	3,36558	85	9	2	852
STMHilir	98,69583	3,3738	54	5	2	545
GunungMeriah	98,64092	3,14904	27	3	0	265
Kutalimbaru	98,50365	3,40395	45	4	0	446
Galang	98,82761	3,44506	32	3	0	320
Birubiru	98,63268	3,3738	28	3	0	276
Sibolangit	98,55032	3,28061	40	4	0	398
Pancurbatu	98,55856	3,43135	18	2	0	174
TanjungMorawa	98,7425	3,50717	7	1	0	70
PagarMerbau	98,79192	3,49438	1	0	0	7
Namorambe	98,61896	3,41217	4	0	0	32

Population of agent in simulation for Asahan District

Sub District	Latitude Reference	Longitude Reference	Population of smallholder in simulation	Population of village supplier in simulation	Population of district supplier in simulation	Population of smallholder in reality
KisaranBarat	99,62325	2,94269	1	0	0	12
Meranti	99,63789	3,05601	9	1	0	88
RawangPancaArga	99,69463	3,01763	11	1	0	110
PuloBandring	99,54088	2,93172	11	1	0	111
SimpangEmpat	99,82275	2,80376	7	1	0	66
TelukDalamAsahan	99,71110	2,69772	10	1	0	102
BuntuPane	99,47865	2,81107	41	4	0	412
TinggiRaja	99,53722	2,74526	56	6	2	555
SetiaJanji	99,47316	2,87322	24	2	0	240
AirBatu	99,65070	2,74891	99	10	2	985
SeiDadap	99,69463	2,84032	70	7	2	702
PulauRakyat	99,71842	2,60082	29	3	0	286
BPMandoge	99,29379	2,71052	25	2	0	245
AekKuasan	99,75686	2,54597	29	3	0	293
AekLedong	99,67450	2,43625	33	3	0	332
BandarPulau	99,39995	2,58254	222	22	2	2222
AekSongsongan	99,31393	2,49660	198	20	2	1978
Rahuning	99,56651	2,65019	7	1	0	68

Population of agent in simulation for Simalungun District

Sub District	Latitude Reference	Longitude Reference	Population of smallholder in simulation	Population of village supplier in simulation	Population of district supplier in simulation	Population of smallholder in reality
TanahJawa	99,1937	2,88406	4	0	0	39
HutaBayuRaja	99,32109	2,96522	2	0	0	15
DolokPanribuan	99,03747	2,76429	10	1	0	102
JorlangHataran	98,99464	2,81255	1	0	0	9
Panei	98,92216	2,90468	5	1	0	52
Raya	98,84199	3,00339	30	3	0	295
DolokSilau	99,14099	2,9389	24	2	0	237
SilauKahean	98,719	3,10866	284	28	2	2835
RayaKahean	98,81124	3,22051	332	33	2	3319
DolokBt.Nanggar	99,15637	3,14726	39	4	0	387
TapianDolok	99,04216	3,07533	34	3	0	336
Siantar	99,14099	2,9389	8	1	0	76
Bandar	99,31187	3,192	31	3	0	309
P.Bandar	99,25081	3,117	2	0	0	17
BosarMaligas	99,39138	3,02883	32	3	0	323
UjungPadang	99,46605	3,01786	29	3	0	288
GunungMalela	99,21918	3,03629	7	1	0	72
GunungMaligas	99,1634	3,06919	2	0	0	15
BandarMasilam	99,29254	3,24989	15	1	0	145
BandarHuluan	99,22138	3,18059	3	0	0	26

PanombeanPane	98,94412	2,96391	3	0	0	30
Hatonduhan	99,16925	2,75551	20	2	0	200
JawaMaraja	99,25037	2,96698	3	0	0	25

Population of agent in simulation for South Tapanuli District

Sub District	**Latitude Reference**	**Longitude Reference**	**Population of smallholder in simulation**	**Population of village supplier in simulation**	**Population of district supplier in simulation**	**Population of smallholder in reality**
BatangAngkola	99,29393	1,31507	349	35	2	3.491
SayurMatinggi	99,37218	1,19842	166	17	2	1657
AngkolaTimur	99,32413	1,56757	10	1	0	97
AngkolaSelatan	99,19784	1,40290	41	4	0	409
AngkolaBarat	99,15666	1,48661	252	25	2	2516
BatangToru	99,04547	1,58267	86	9	2	856
Marancar	99,13881	1,56346	343	34	2	3434
Sipirok	99,20059	1,64853	78	8	2	782
Arse	99,22667	1,74184	81	8	2	805
SaiporDolokHole	99,26373	1,84749	91	9	2	908
AekBilah	99,27060	1,96822	1.037	104	2	10365
MuaraBatangToru	98,92467	1,41114	118	12	2	1.179
TantomAngkola	99,42983	1,10509	72	7	2	715
AngkolaSangkunur	99,08116	1,41525	93	9	2	933

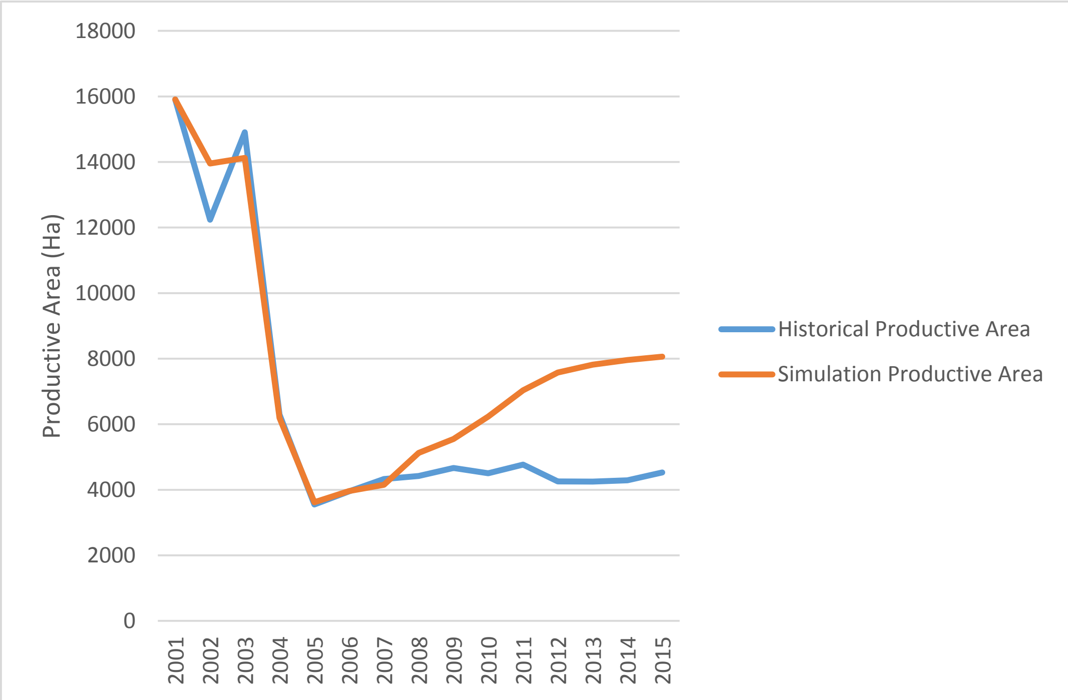
Appendix D Operational Validation Results

D.1 Historical Validation of Deli Serdang District

Deli Serdang is one big district in North Sumatera, which faces a reduction of natural rubber supply. This reduction trend can be observed in historical data of Deli Serdang District. The reduction of supply was mainly caused by many productive areas entering non-productive phase. It can be seen in figure 5.18, productive area in Deli Serdang reduced at 2003 from around 14,000 hectares to be around 6,000 hectares. Unfortunately, this reduction was not followed by massive replanting or opening new plantation. This could be detected by total of immature area for this district that was less than 1,000 hectares per year since 2004 except for 2009, 2010, 2011 and 2015. This circumstance leads to decline natural rubber production.

It can be observed in figure below, simulation result for Deli Serdang District presented similar trend with historical data. In term of productive area, simulation result followed reduction trend of historical data particularly at 2003. However, the difference started to appear after 2009, in simulation result productive area increased to around 5,500 hectares while the productive area in historical data remained constant at around 4,200 hectares. The increasing of productive area in simulation result was caused by immature area since 2001 entering productive phase. As stated in table below, in initial data for simulation, there was 3,200 hectares immature area. Nevertheless, in historical data, the productive area remained constant at around 4,000 hectares since 2007 until 2015 although there was more than 1,500 hectares immature area at 2001, 2002 and 2003 that should become productive since 2007.

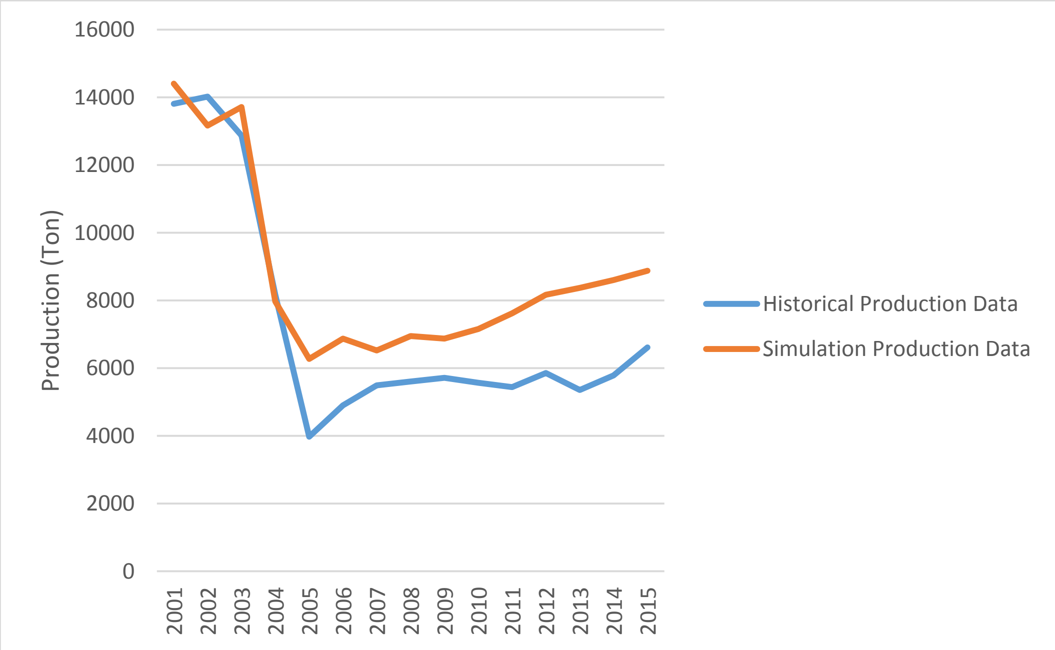
In term of production, simulation result presented decreasing trend of latex production similar with historical data. However, the difference showed up since 2005 where simulation result generated higher latex production data compared to historical data. The reason for this was due to productive area in simulation result within this time was higher than productive area in historical data. The Higher productive area in simulation result was lead to higher latex production since latex production mainly depended on productive area.



Comparison of Simulation Productive Area Data with Historical Productive Data for Deli Serdang District

Productive Area Difference between Simulation and Historical Data for Deli Serdang District

Year	**Productive area Difference (Y)**	**(Y^2)**
2001	0.00	0.00
2002	1711.00	2927521.00
2003	785.00	616225.00
2004	101.00	10201.00
2005	70.00	4900.00
2006	8.00	64.00
2007	179.00	32041.00
2008	703.01	494221.64
2009	883.34	780283.86
2010	1729.01	2989460.21
2011	2266.21	5135726.83
2012	3323.75	11047333.58
2013	3566.92	12722906.07
2014	3666.90	13446136.61
2015	3533.41	12485012.11
Total Difference	**22526.55**	**62692032.92**
MAE/MSE	**1501.77**	**4179468.86**



Comparison of Simulation Production Data with Historical Production Data for Deli Serdang District

Production Difference between Simulation and Historical Data for Deli Serdang District

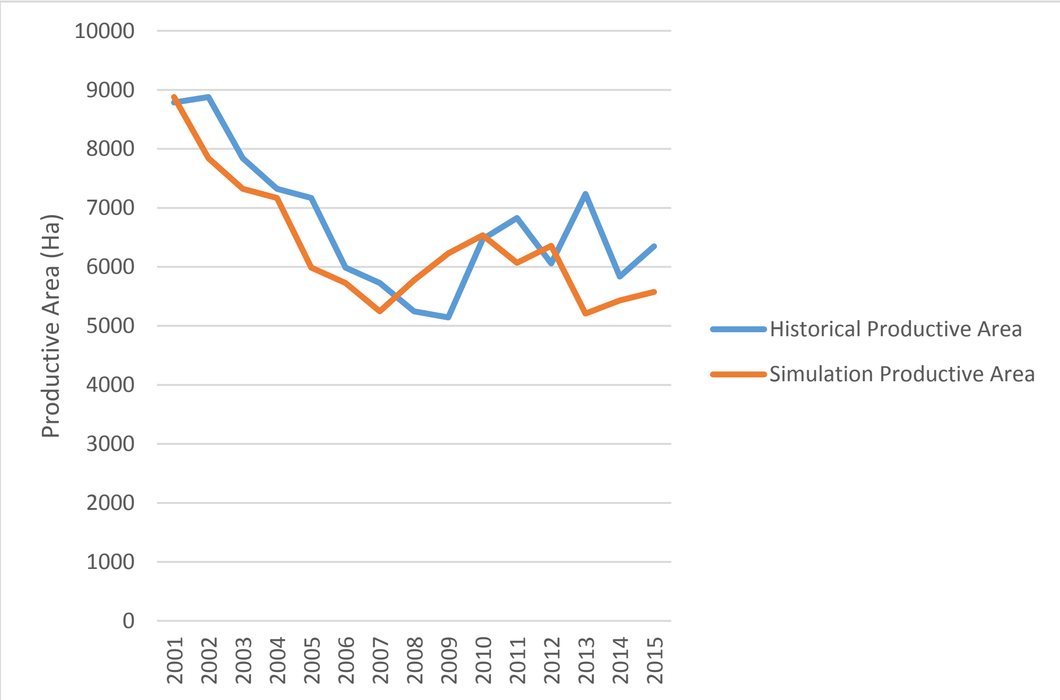
Year	**Production Difference (X)**	**(X^2)**
2001	596.40	355692.96
2002	854.16	729584.24
2003	844.33	712891.21
2004	203.44	41389.36
2005	2299.04	5285568.65
2006	1971.01	3884876.77
2007	1028.74	1058305.33
2008	1342.33	1801843.27
2009	1158.70	1342577.84
2010	1588.47	2523243.28
2011	2180.89	4756295.49
2012	2313.85	5353924.00
2013	3014.76	9088807.43
2014	2816.81	7934426.92
2015	2264.99	5130160.69
Total Difference	**24477.92**	**49999587.45**
MAE/MSE	**1631.86**	**3333305.83**

D.2 Historical Validation for Asahan District

Asahan is one district with big rubber plantation area. Currently, this district has more than 6,000 hectares rubber plantation. Some rubber primary processors are located in this district. Historical data related to rubber plantation indicated a small reduction in productive area in last 15 years from around 8,700 hectares in 2001 to be around 6,300 hectares in 2015. This reduction was caused by many productive areas entering non-productive phase since 2001 until 2007. Unfortunately, this condition was not covered by replanting and opening new rubber plantation. It can be seen from historical data that total immature area was steady under 500 hectares since 2003 until 2012.

The simulation was run by using initial data from 2001 to predict the change in productive area and latex production for Asahan District. It can be observed in figure below that simulation result presented similar trend for productive area, which there was reduction of productive area until 2007. This was followed by a slightly increase of productive area from around 5,200 hectares at 2008 to be around 6,500 at 2010. However, small differences were found between simulation result and historical data. The differences occurred particularly while there was a significant increase in productive area at historical data. For example, at 2010 and 2013, there were a jump around 1,000 hectares in productive area of historical data. However, these circumstances seem unnatural since total immature area at 2009 and 2012 in historical data were less than 300 hectares and these amounts were not enough to cover the addition of 1,000 hectares in the productive area at 2010 and 2013. The simulation follows the life cycle of rubber plantation where additional areas in the productive area are generated from total immature areas that become productive at that year.

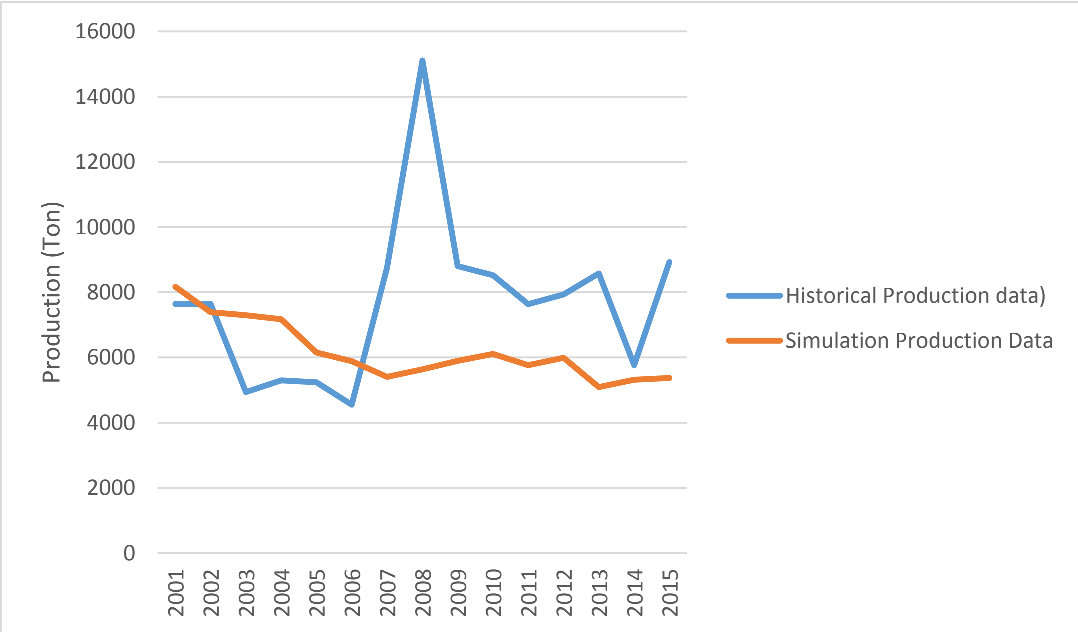
Although there was not much different in term of productive area, big differences were found while compared simulation result and historical data for latex production. It can be seen in figure below; latex production data in historical data seems volatile while simulation generated steady latex production with a slight reduction in first three years. As the result, big differences occurred particularly at 2007, 2008 and 2013. There was no further explanation in historical data for fluctuation in latex production. At 2008, there was a big jump in latex production for historical data from around 8,700 ton to around 15,000 ton. This situation seemed unreasonable while the total productive area was steady at around 5,200 hectares at 2008. Latex production data in simulation result reflected total productive area. As the result, the increasing of latex production must be produced from escalating the productive area.



Comparison of Simulation Productive Area Data with Historical Productive Data for Asahan District

Productive Area Difference between Simulation and Historical Data for Asahan District

Year	**Productive area Difference (Y)**	**(Y^2)**
2001	91.00	8281.00
2002	1037.00	1075369.00
2003	517.00	267289.00
2004	155.00	24025.00
2005	1181.00	1394761.00
2006	262.00	68644.00
2007	479.00	229441.00
2008	525.99	276664.37
2009	1084.66	1176493.26
2010	62.74	3936.67
2011	758.96	576026.43
2012	299.33	89595.91
2013	2026.95	4108529.32
2014	403.23	162593.14
2015	774.04	599142.36
Total Difference	**9657.91**	**10060791.46**
MAE/MSE	**643.86**	**670719.43**



Comparison of Simulation Production Data with Historical Production Data for Asahan District

Production Difference between Simulation and Historical Data for Asahan District

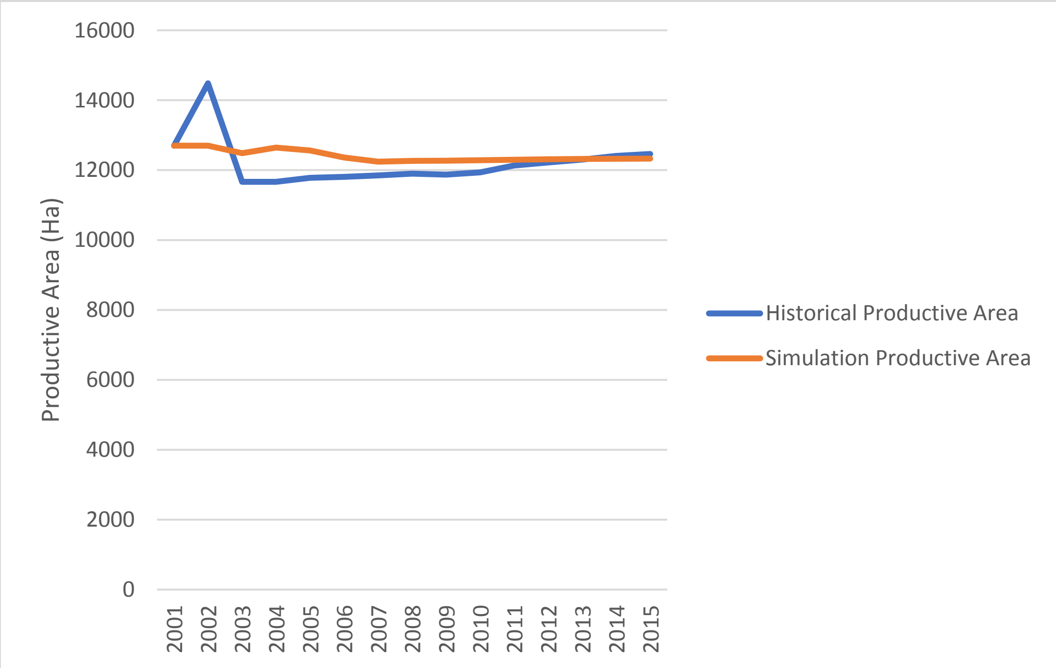
Year	**Production Difference (X)**	**(X^2)**
2001	525.70	276360.49
2002	254.65	64844.35
2003	2353.34	5538195.64
2004	1874.55	3513923.84
2005	913.24	834003.82
2006	1334.97	1782140.24
2007	3353.53	11246172.97
2008	9474.77	89771308.35
2009	2910.08	8468552.06
2010	2414.89	5831715.95
2011	1872.77	3507268.13
2012	1944.20	3779929.83
2013	3484.39	12140952.14
2014	448.02	200724.49
2015	3554.23	12632529.13
Total Difference	**36713.32**	**159588621.43**
MAE/MSE	**2447.55**	**10639241.43**

D.3 Historical Validation for Simalungun District

Simalungun is one big district located in middle of North Sumatera province. This district is famous as a source for good quality of rubber seed in North Sumatera. There is more than 11,000 hectares rubber plantations area in this district, which shows the importance of this district for supplying latex. Historical data shows the stable trend in this district for total of productive area and latex production in last 15 years.

The simulation was run using initial data from Simalungun's historical data (data from year 2001). It can be observed in figure below that simulation result follows the trend in historical data. Simulation produced stable trend for the productive area which total productive area for Simalungun district was predicted to stay at around 12.000 Hectares. Hence, small differences were detected between simulation result and historical data. The big differences were found at year 2002. There was a big increase of productive area in historical data from around 11,000 Ha to around 14,000 Ha. This increasing seems unnatural since there was only around 300 Ha as immature area at historical data. Total of immature area was not enough to support the increasing trend at year 2002. Simulation follows life cycle of rubber plantation where the increase of productive area is resulted from immature area that enters productive phase. Hence, in simulation result, the increase of productive area at year 2002 did not appear since there was not enough the immature area at year 2001.

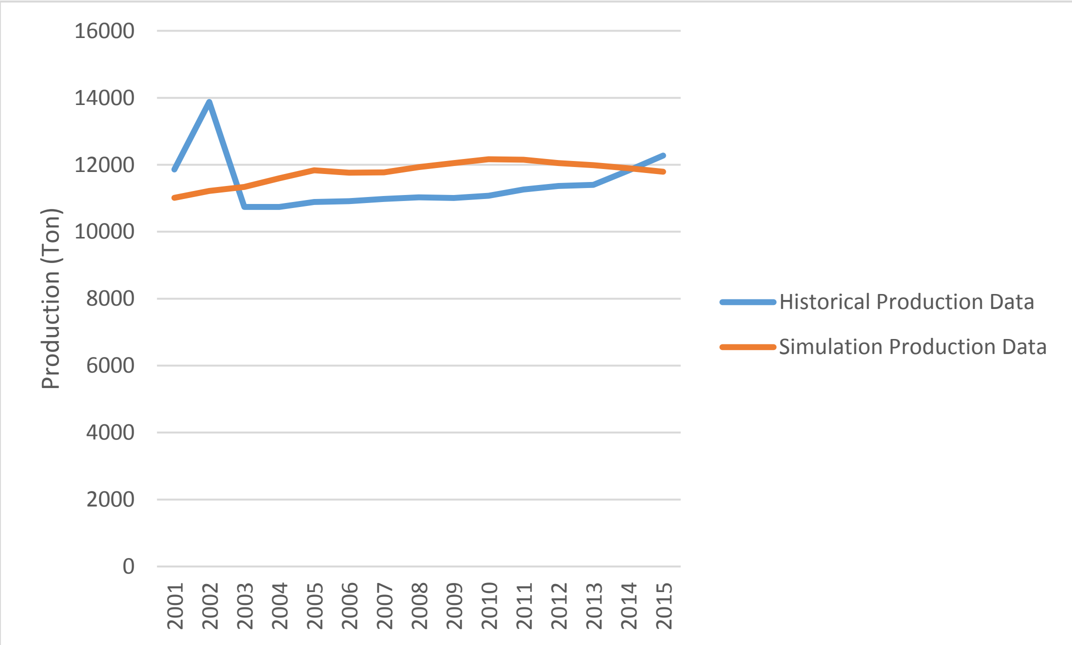
The similar trend can be observed in the comparison between latex production data in historical data and simulation result. Figure below shows that small differences were produced during comparison. The big difference was found only at year 2002. At this year, there was a big increase in latex production at historical data. This increase was caused by the growth of productive area in historical data at year 2002. Since in simulation, the productive area remained same at around 12,000 Ha, there was no increase of latex production at year 2002 in simulation result.



Comparison of Simulation Productive Area Data with Historical Hroductive Data for Simalungun District

Productive Area Difference between Simulation and Historical Data for Simalungun District

Year	Productive area Difference (Y)	(Y^2)
2001	0.00	0.00
2002	1786.00	3189796.00
2003	821.00	674041.00
2004	983.00	966289.00
2005	784.00	614656.00
2006	555.00	308025.00
2007	393.20	154606.24
2008	366.15	134069.06
2009	401.63	161309.46
2010	350.42	122795.25
2011	167.18	27949.32
2012	94.30	8891.84
2013	21.60	466.67
2014	79.42	6307.75
2015	134.41	18064.77
Total Difference	**6937.32**	**6387267.35**
MAE/MSE	**462.49**	**425817.82**



Comparison of Simulation Production Data with Historical Production Data for Simalungun District

Production Difference between Simulation and Historical Data for Simalungun District

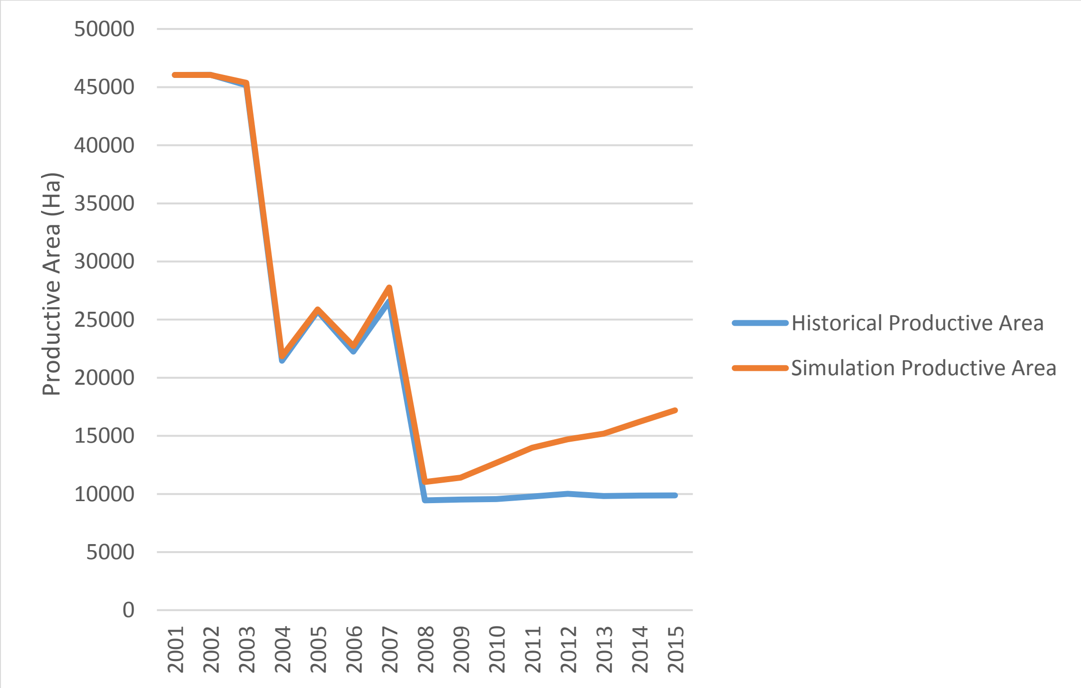
Year	Production Difference (X)	(X^2)
2001	844.88	713813.77
2002	2658.00	7064956.20
2003	597.76	357316.15
2004	855.36	731646.67
2005	950.62	903682.68
2006	852.18	726206.17
2007	793.75	630038.88
2008	902.36	814257.41
2009	1041.81	1085360.42
2010	1093.04	1194742.78
2011	887.00	786760.43
2012	684.55	468602.70
2013	586.41	343877.74
2014	71.46	5106.88
2015	482.85	233145.80
Total Difference	**13302.02**	**16059514.67**
MAE/MSE	**886.80**	**1070634.31**

D.4 Historical Validation for South Tapanuli District

South Tapanuli is big district located on south side of North Sumatera. This district is one of source latex for North Sumatera since 1990. However, this district faces a reduction of natural rubber supply since 2000. It can be observed from historical data of South Tapanuli district that there was a massive reduction of productive area particularly in 2007. At this year, there was a big decline in the productive area from around 26,000 Ha to only around 9,000 Ha. This reduction was indicated to be caused by many productive areas entered non-productive phase. Half of these areas have been converted to other crops. The rest of non-productive area is keeping old rubber tree. This condition has caused reduction of latex production from South Tapanuli district.

The simulation was performed by using initial data from South Tapanuli district (data from year 2001). The simulation has succeeded to produce similar trend with historical data for the productive area as shown in figure below. However, big differences between simulation result and historical data were detected starting from year 2008. Simulation result produced an increasing trend in the productive area since year 2008 while in historical data, the productive area remained constant at around 10,000 Ha. The increasing trend in simulation result was caused by immature area since 2001 starting to become productive. Historical data presented unnatural condition while there was no additional area in the productive area since 2008 although total of immature area was high (more than 10,000 Ha) in historical data since 2001 until 2007.

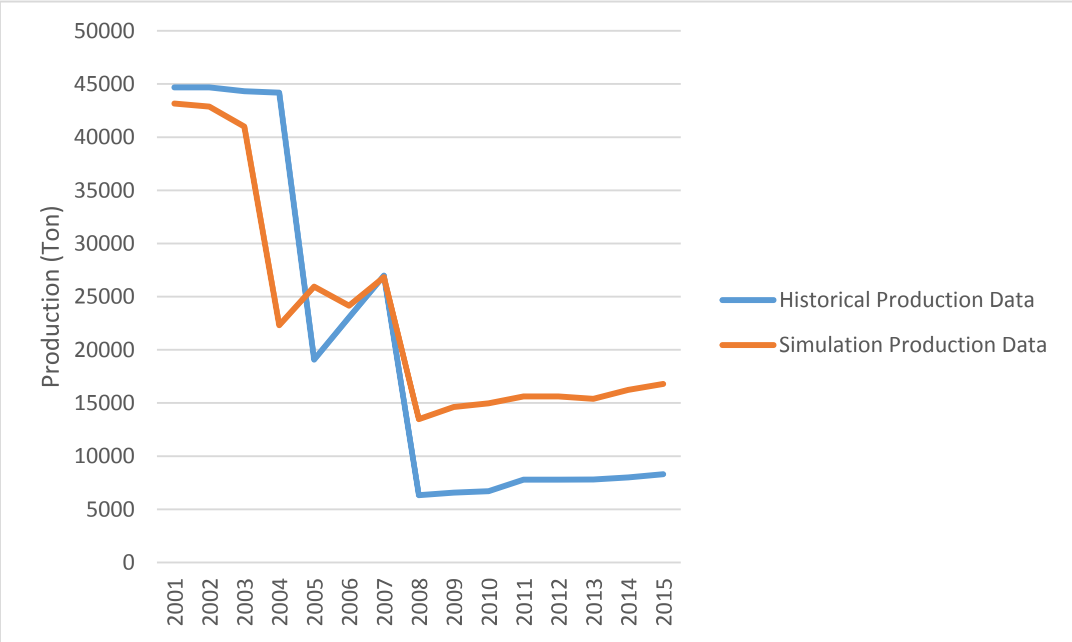
The differences in the productive area have triggered the differences in comparison for latex production. It can be observed from figure below that there was a big difference in latex production since year 2008. This was due to the productive area in simulation result was higher than the productive area in historical data. As the result, latex production in simulation result was higher than latex production in historical data since year 2008. Total latex production in the simulation is mainly depended to total of productive area.



Comparison of Simulation Productive Area Data with Historical Productive Data for South Tapanuli District

Productive Area Difference between Simulation and Historical Data for South Tapanuli District

Year	Productive area Difference (Y)	(Y^2)
2001	0.00	0.00
2002	4.00	16.00
2003	196.00	38416.00
2004	396.00	156816.00
2005	146.00	21316.00
2006	478.00	228484.00
2007	1193.00	1423249.00
2008	1587.33	2519626.94
2009	1876.18	3520046.70
2010	3129.90	9796255.49
2011	4194.76	17596004.19
2012	4692.46	22019181.51
2013	5372.79	28866856.32
2014	6329.62	40064065.18
2015	7323.85	53638851.89
Total Difference	**36919.89**	**179889185.20**
MAE/MSE	**2461.33**	**11992612.35**



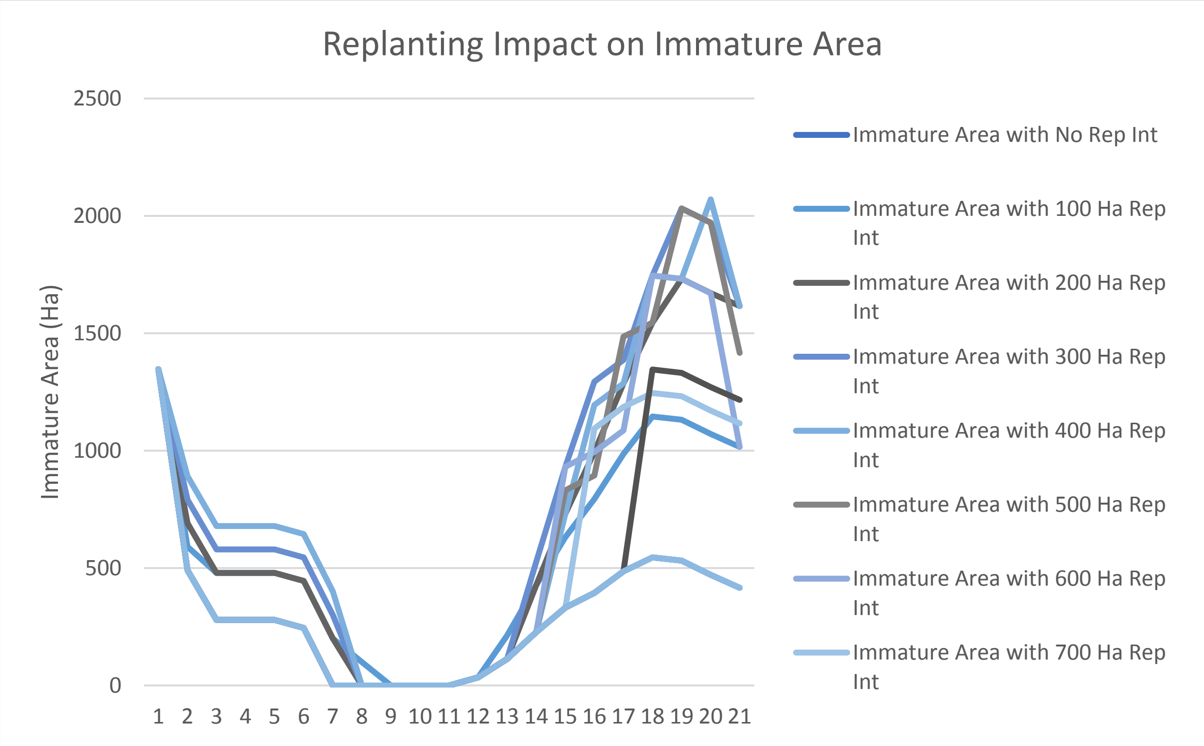
Comparison of Simulation Production Data with Historical Production Data for South Tapanuli District

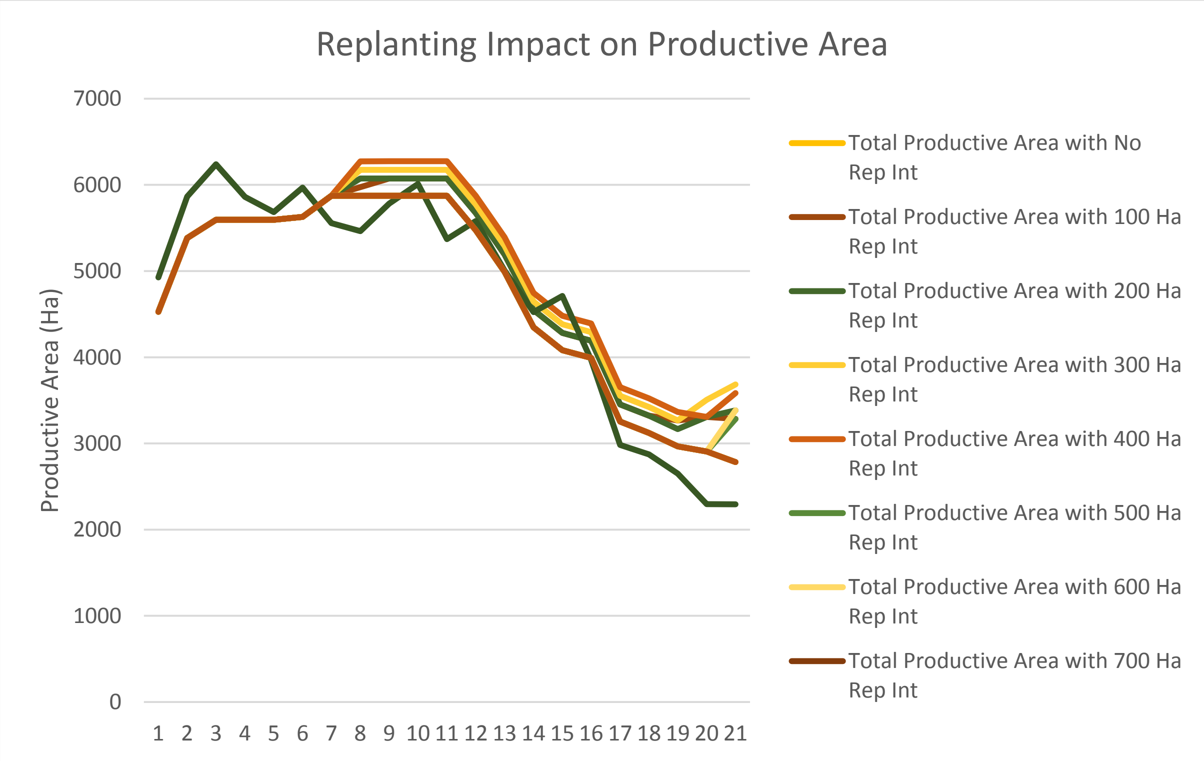
Production Difference between Simulation and Historical Data for South Tapanuli District

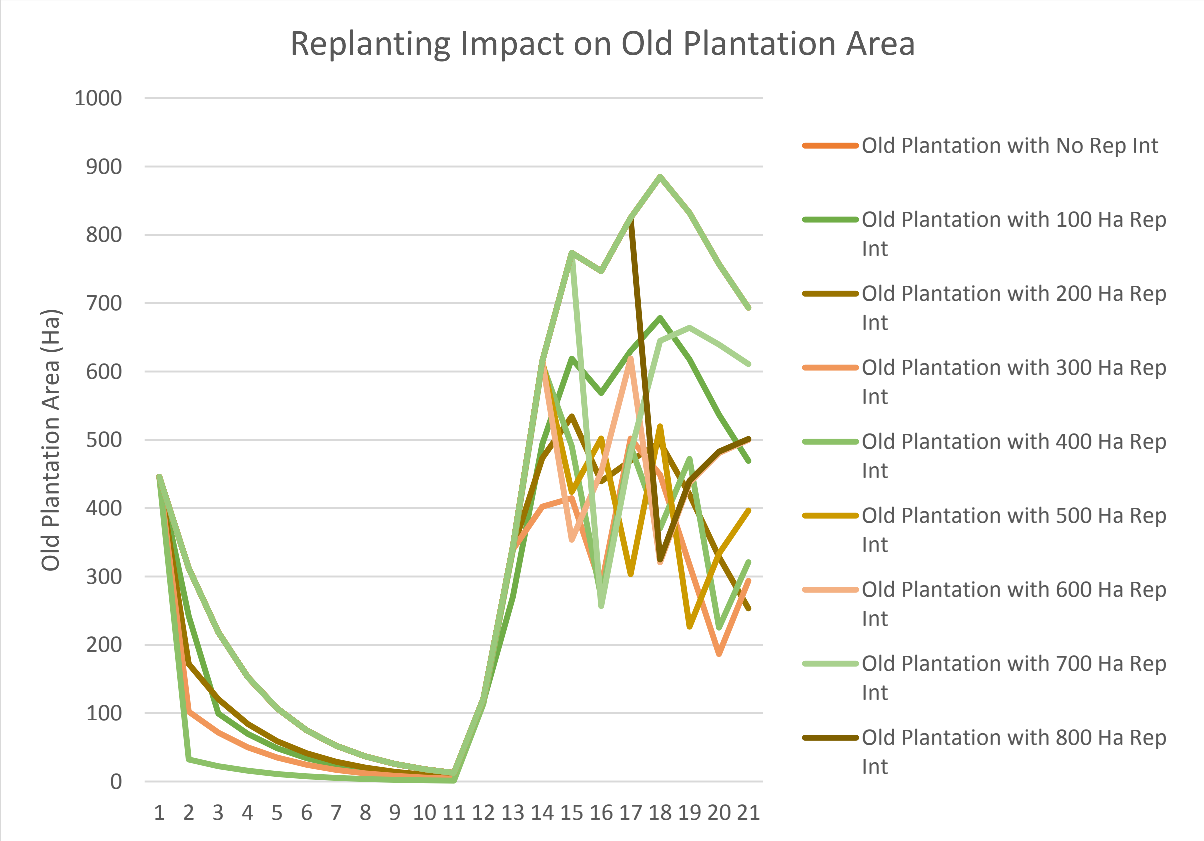
Year	Production Difference (X)	(X^2)
2001	1522.80	2318919.84
2002	1802.06	3247435.06
2003	3338.85	11147931.08
2004	21871.12	478346046.89
2005	6851.71	46945987.28
2006	1098.31	1206291.61
2007	157.42	24781.74
2008	7154.84	51191748.14
2009	8054.29	64871535.81
2010	8269.95	68392002.70
2011	7830.48	61316400.27
2012	7814.30	61063274.59
2013	7586.26	57551278.01
2014	8241.48	67921940.08
2015	8494.35	72154020.51
Total Difference	**100088.23**	**1047699593.62**
MAE/MSE	**6672.55**	**69846639.57**

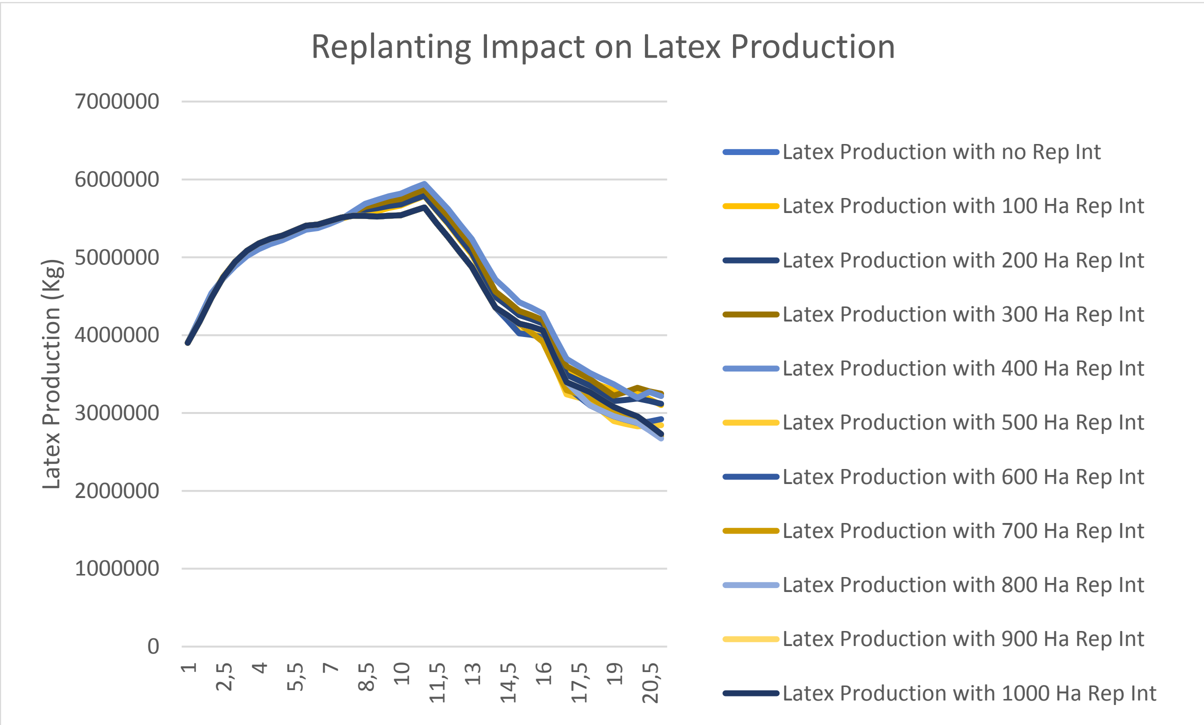
Appendix E Simulation Result for Other Districts

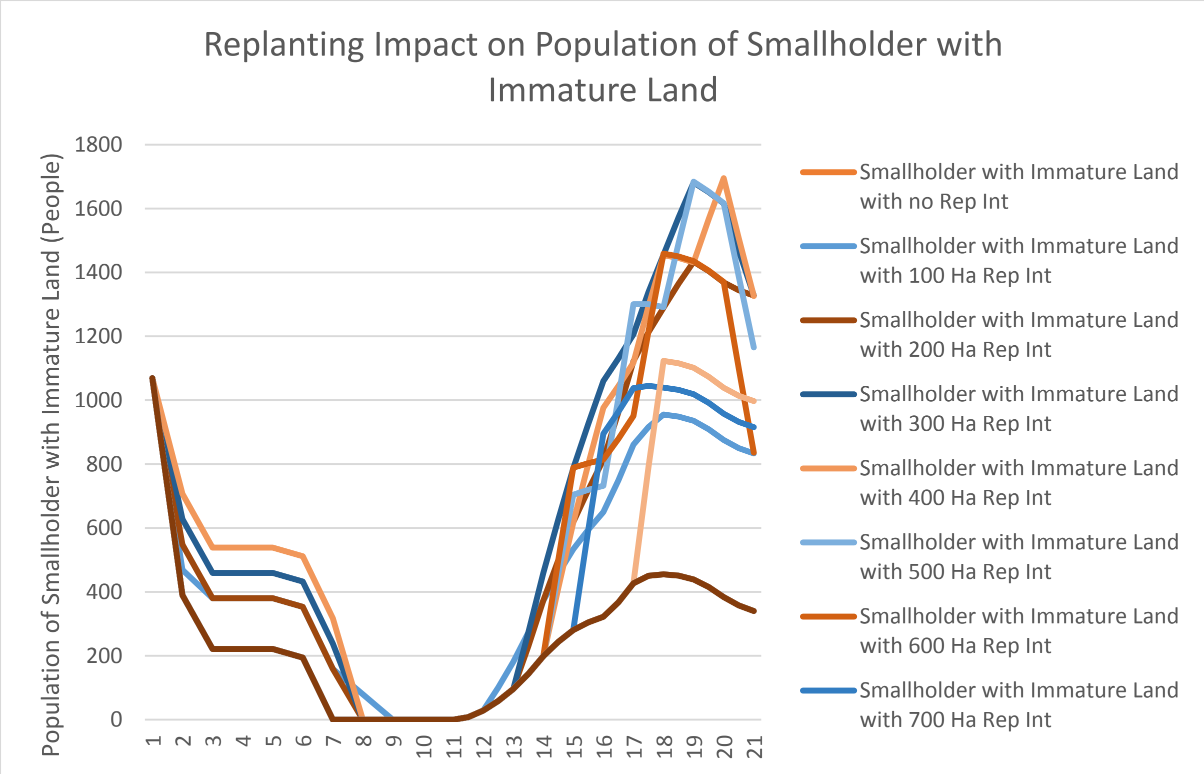
E.1 Simulation Result for Deli Serdang District

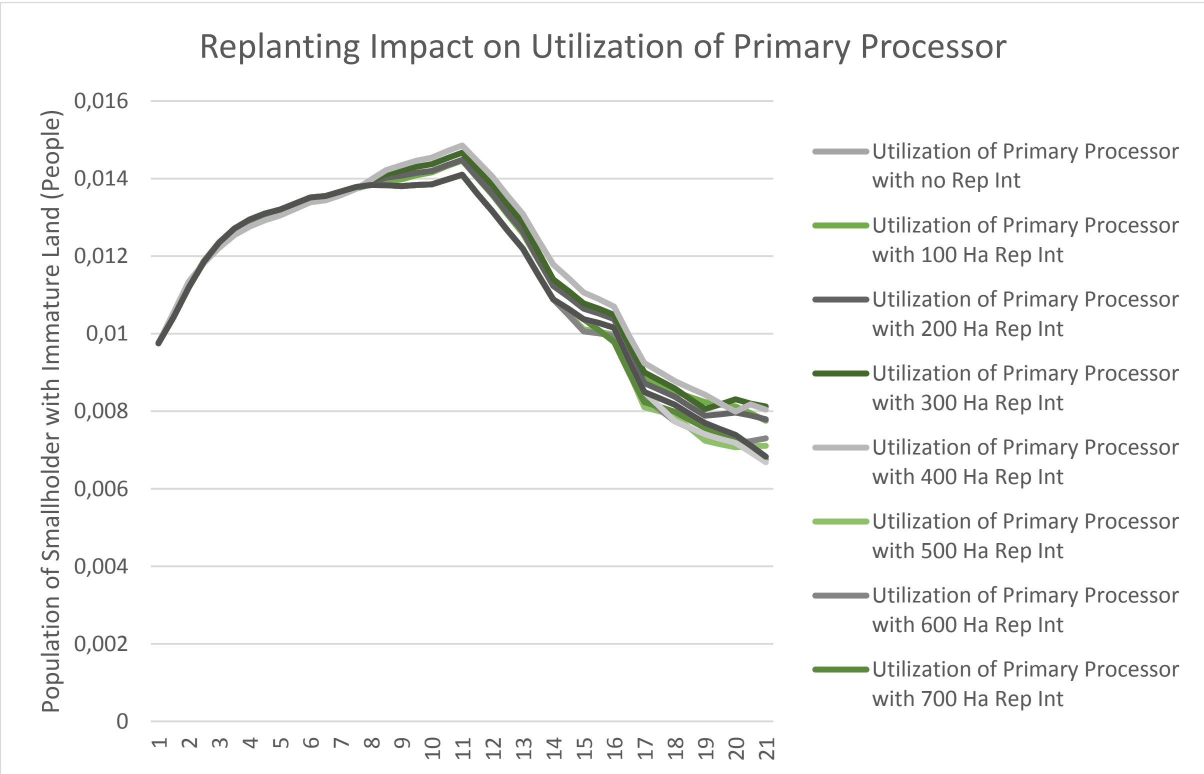


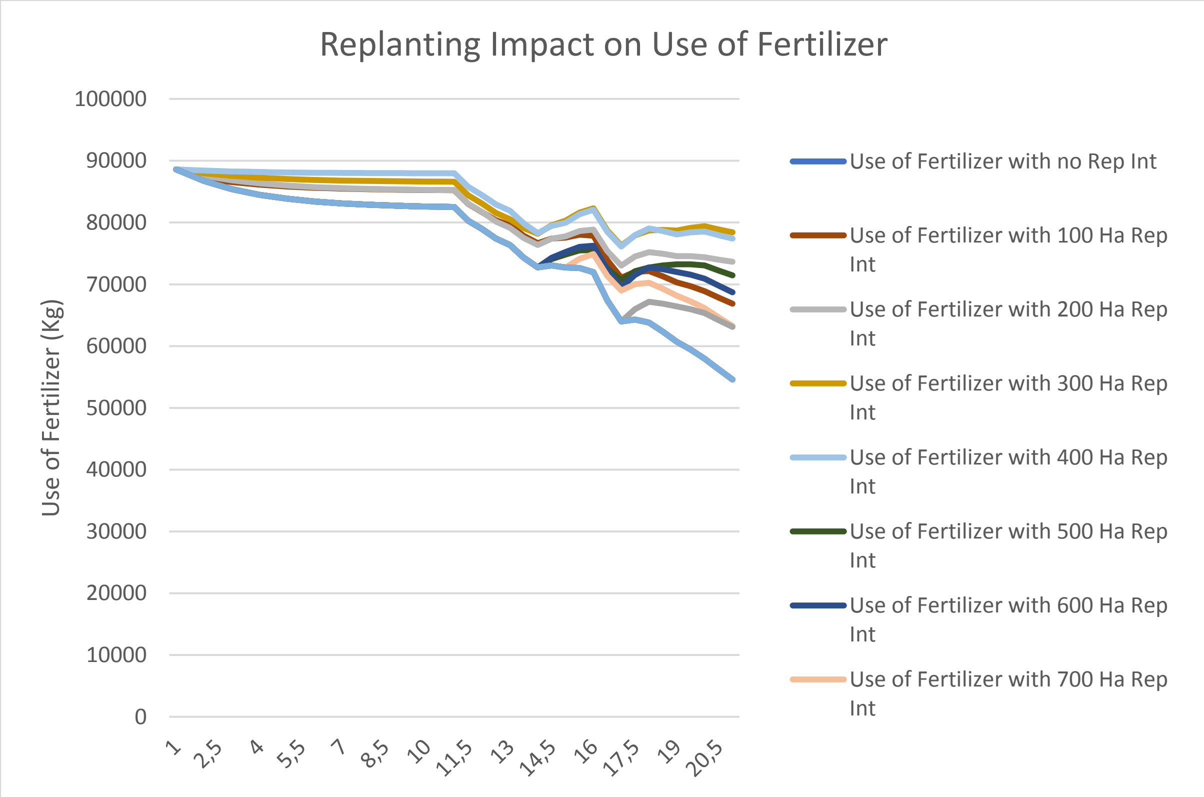


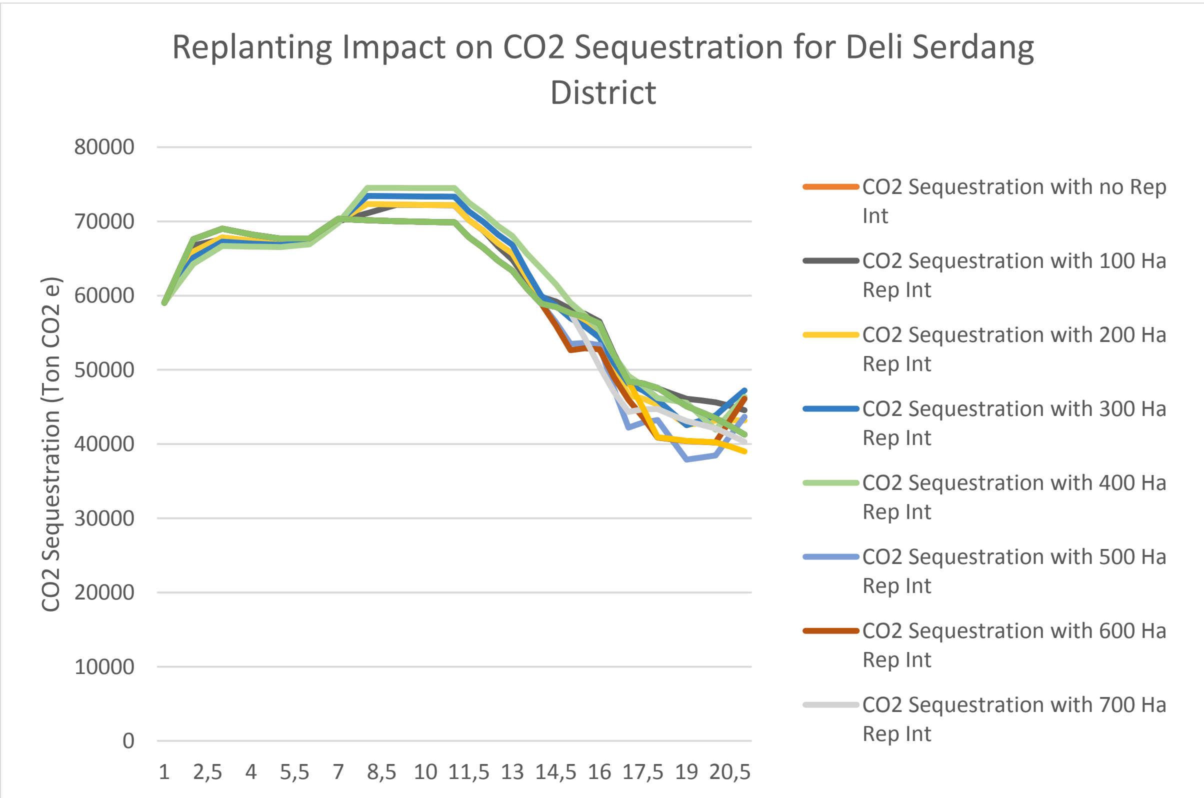

Replanting Impact on Old Plantation Area
Old Plantation Area (Ha)
1000
900
800
700
600
500
400
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Old Plantation with No Rep Int
Old Plantation with 100 Ha Rep Int
Old Plantation with 200 Ha Rep Int
Old Plantation with 300 Ha Rep Int
Old Plantation with 400 Ha Rep Int
Old Plantation with 500 Ha Rep Int
Old Plantation with 600 Ha Rep Int
Old Plantation with 700 Ha Rep Int
Old Plantation with 800 Ha Rep Int

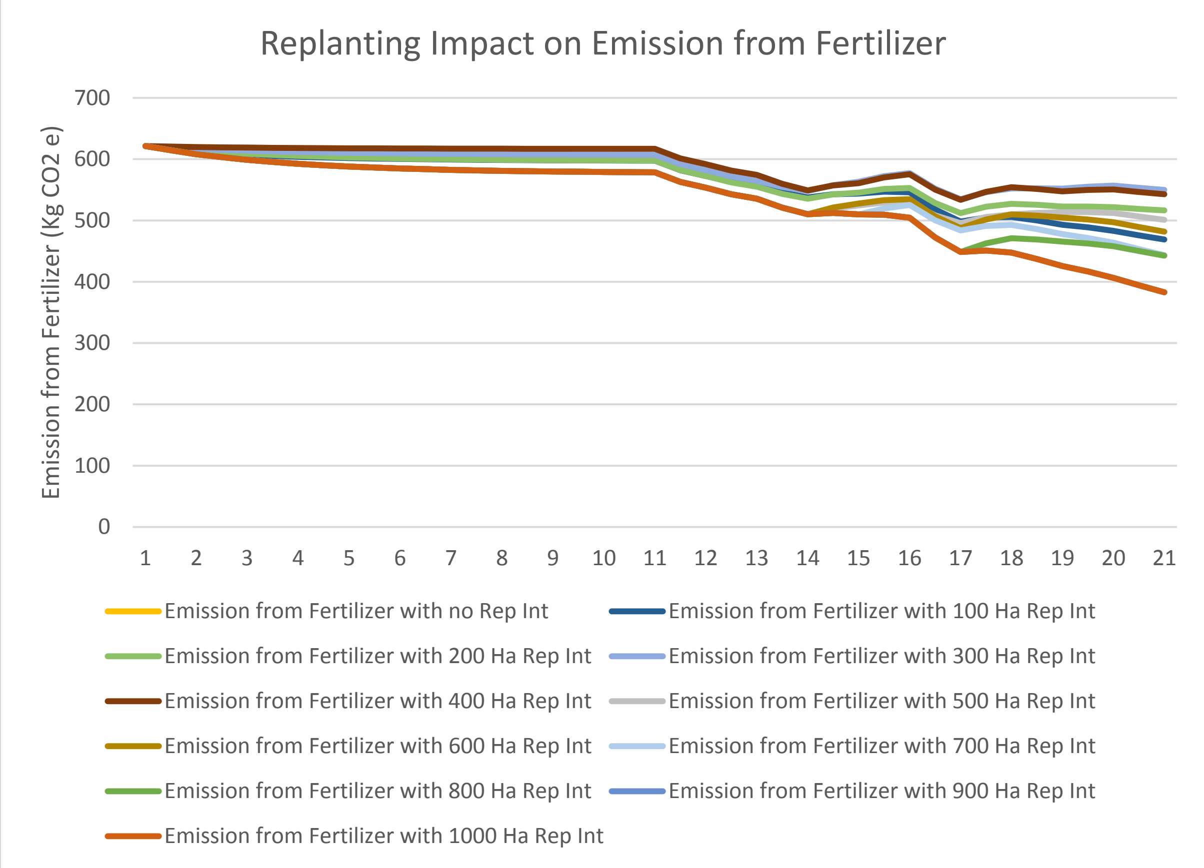

Replanting Impact on Latex Production
Latex Production (Kg)
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
Latex Production with no Rep Int
Latex Production with 100 Ha Rep Int
Latex Production with 200 Ha Rep Int
Latex Production with 300 Ha Rep Int
Latex Production with 400 Ha Rep Int
Latex Production with 500 Ha Rep Int
Latex Production with 600 Ha Rep Int
Latex Production with 700 Ha Rep Int
Latex Production with 800 Ha Rep Int
Latex Production with 900 Ha Rep Int
Latex Production with 1000 Ha Rep Int


Replanting Impact on Population of Smallholder with Immature Land
Population of Smallholder with Immature Land (People)
1800
1600
1400
1200
1000
800
600
400
200
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Smallholder with Immature Land with no Rep Int
Smallholder with Immature Land with 100 Ha Rep Int
Smallholder with Immature Land with 200 Ha Rep Int
Smallholder with Immature Land with 300 Ha Rep Int
Smallholder with Immature Land with 400 Ha Rep Int
Smallholder with Immature Land with 500 Ha Rep Int
Smallholder with Immature Land with 600 Ha Rep Int
Smallholder with Immature Land with 700 Ha Rep Int

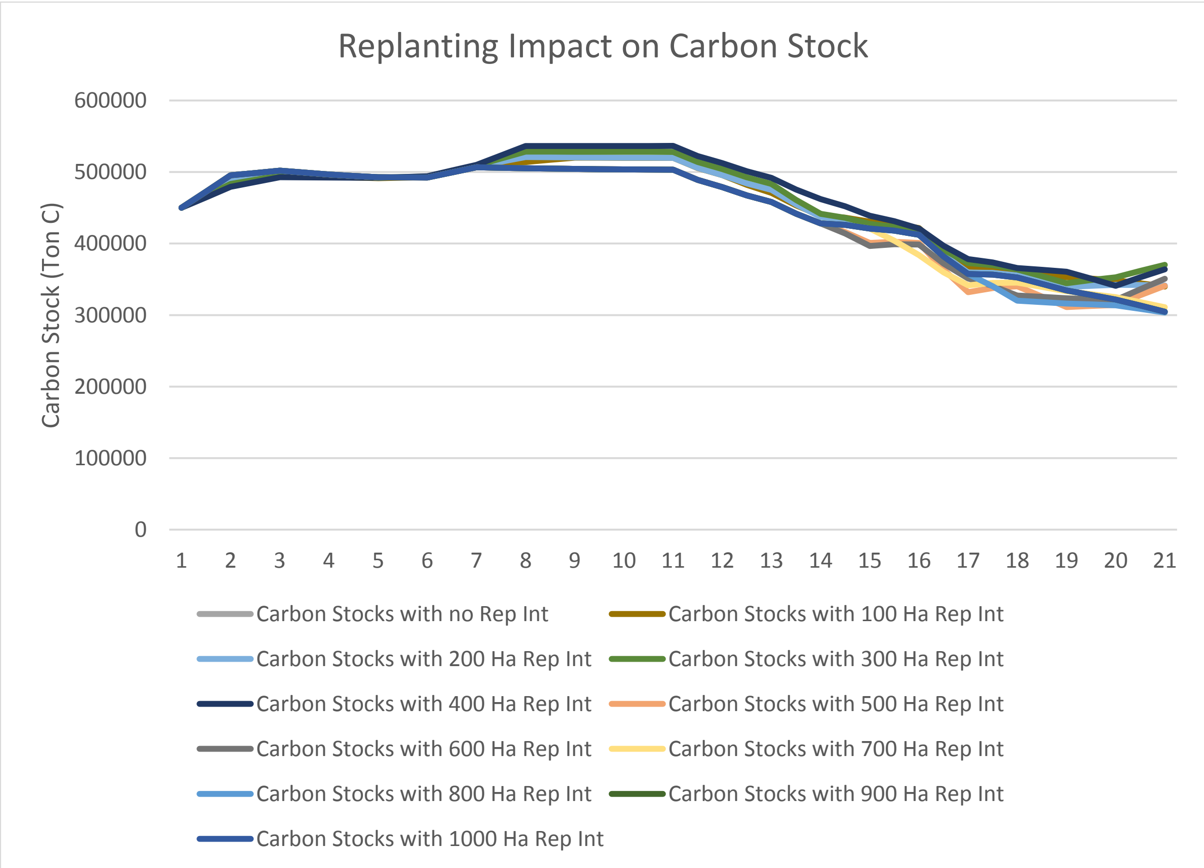

Replanting Impact on Utilization of Primary Processor
Population of Smallholder with Immature Land (People)
0,016
0,014
0,012
0,01
0,008
0,006
0,004
0,002
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Utilization of Primary Processor with no Rep Int
Utilization of Primary Processor with 100 Ha Rep Int
Utilization of Primary Processor with 200 Ha Rep Int
Utilization of Primary Processor with 300 Ha Rep Int
Utilization of Primary Processor with 400 Ha Rep Int
Utilization of Primary Processor with 500 Ha Rep Int
Utilization of Primary Processor with 600 Ha Rep Int
Utilization of Primary Processor with 700 Ha Rep Int


Replanting Impact on Use of Fertilizer
Use of Fertilizer (Kg)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
Use of Fertilizer with no Rep Int
Use of Fertilizer with 100 Ha Rep Int
Use of Fertilizer with 200 Ha Rep Int
Use of Fertilizer with 300 Ha Rep Int
Use of Fertilizer with 400 Ha Rep Int
Use of Fertilizer with 500 Ha Rep Int
Use of Fertilizer with 600 Ha Rep Int
Use of Fertilizer with 700 Ha Rep Int

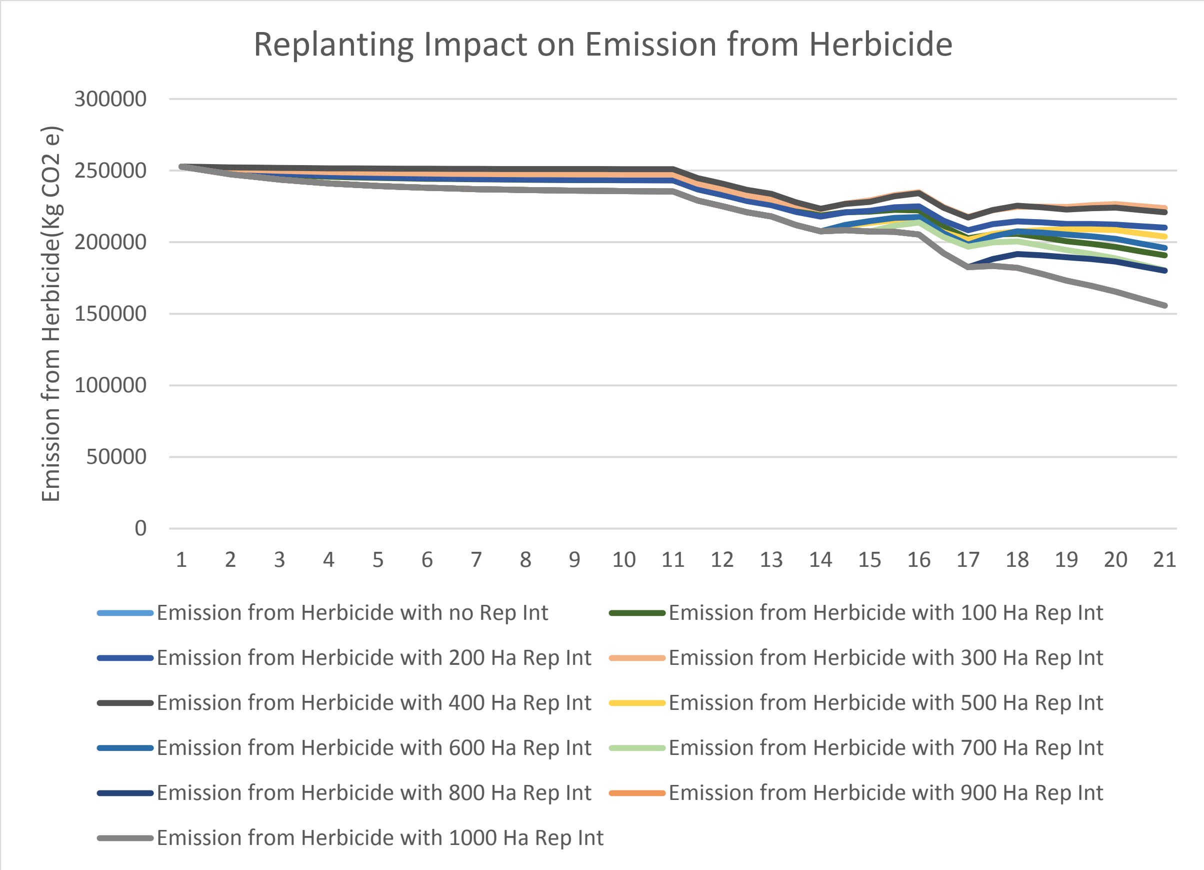

Replanting Impact on CO2 Sequestration for Deli Serdang District
CO2 Sequestration (Ton CO2 e)
80000
70000
60000
50000
40000
30000
20000
10000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
CO2 Sequestration with no Rep Int
CO2 Sequestration with 100 Ha Rep Int
CO2 Sequestration with 200 Ha Rep Int
CO2 Sequestration with 300 Ha Rep Int
CO2 Sequestration with 400 Ha Rep Int
CO2 Sequestration with 500 Ha Rep Int
CO2 Sequestration with 600 Ha Rep Int
CO2 Sequestration with 700 Ha Rep Int

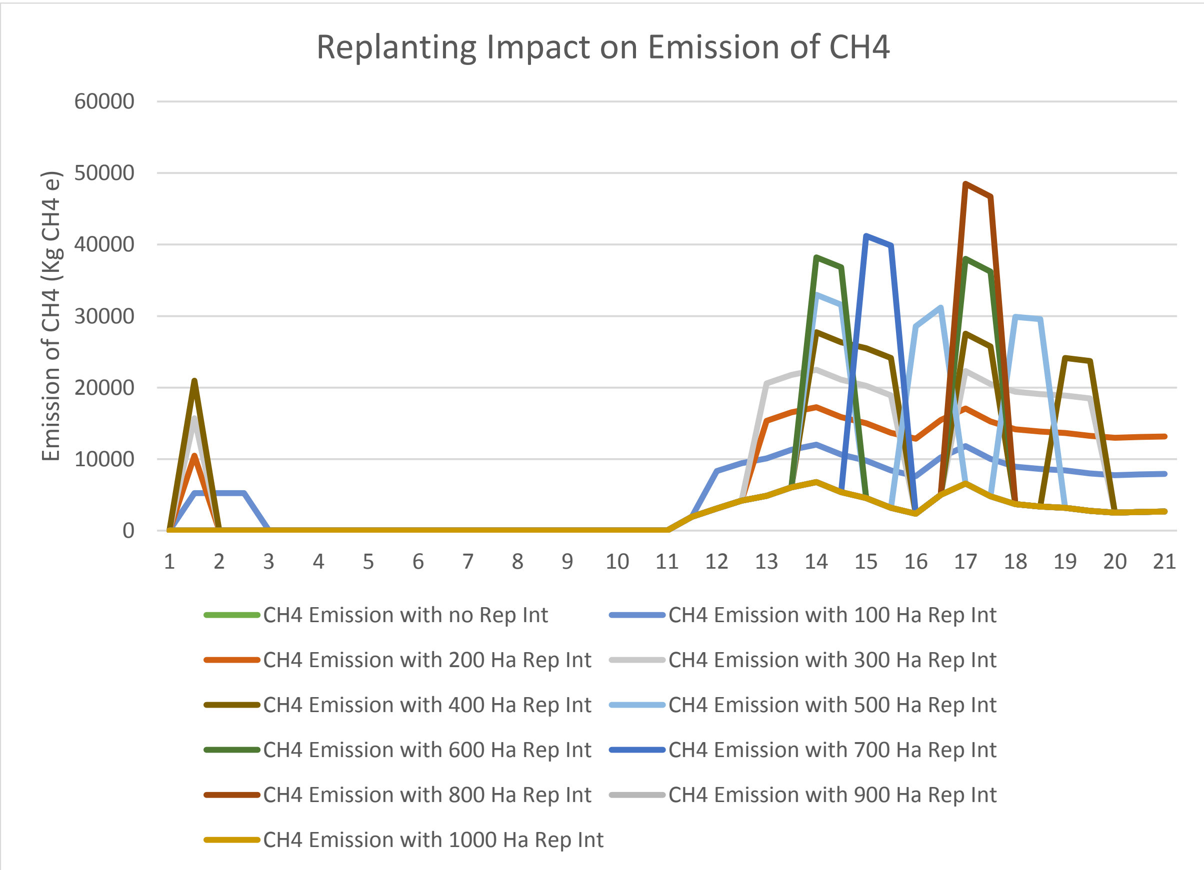


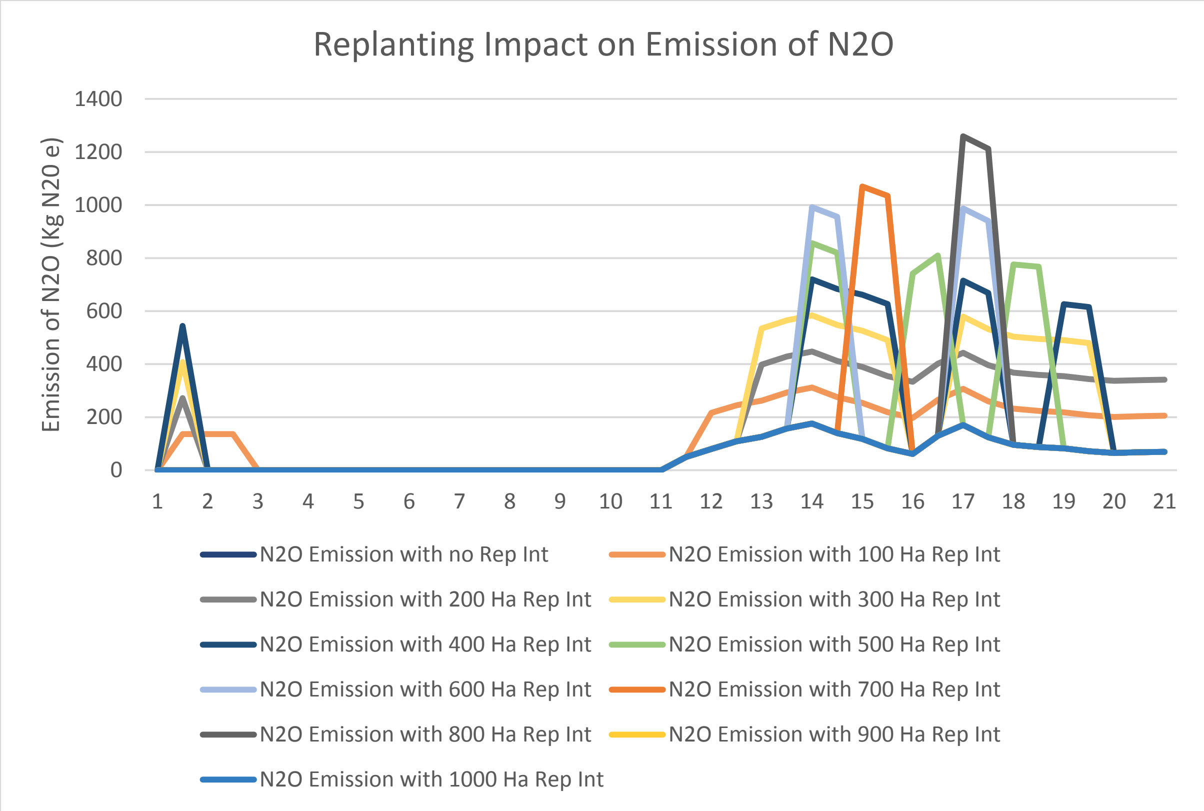
Replanting Impact on Emission from Fertilizer
Emission from Fertilizer (Kg CO2 e)
700
600
500
400
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Emission from Fertilizer with no Rep Int
Emission from Fertilizer with 100 Ha Rep Int
Emission from Fertilizer with 200 Ha Rep Int
Emission from Fertilizer with 300 Ha Rep Int
Emission from Fertilizer with 400 Ha Rep Int
Emission from Fertilizer with 500 Ha Rep Int
Emission from Fertilizer with 600 Ha Rep Int
Emission from Fertilizer with 700 Ha Rep Int
Emission from Fertilizer with 800 Ha Rep Int
Emission from Fertilizer with 900 Ha Rep Int
Emission from Fertilizer with 1000 Ha Rep Int



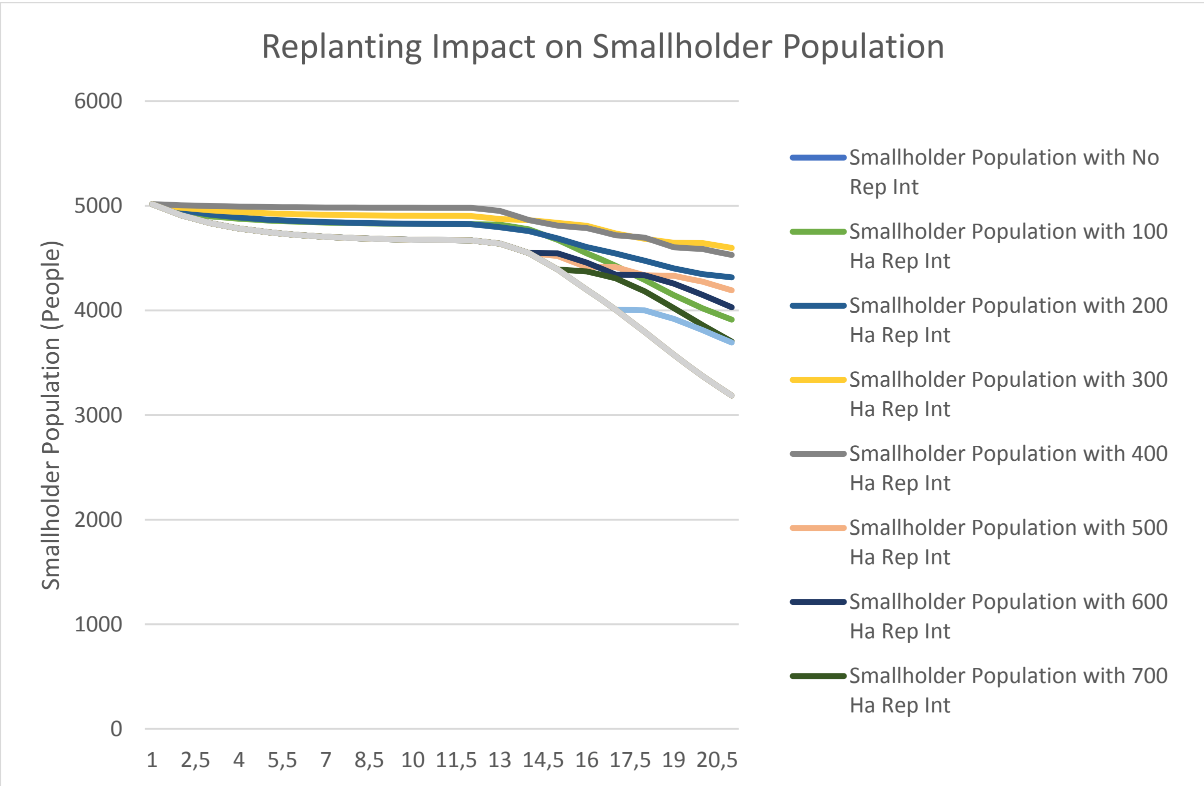
Replanting Impact on Carbon Stock
Carbon Stock (Ton C)
600000
500000
400000
300000
200000
100000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Carbon Stocks with no Rep Int
Carbon Stocks with 100 Ha Rep Int
Carbon Stocks with 200 Ha Rep Int
Carbon Stocks with 300 Ha Rep Int
Carbon Stocks with 400 Ha Rep Int
Carbon Stocks with 500 Ha Rep Int
Carbon Stocks with 600 Ha Rep Int
Carbon Stocks with 700 Ha Rep Int
Carbon Stocks with 800 Ha Rep Int
Carbon Stocks with 900 Ha Rep Int
Carbon Stocks with 1000 Ha Rep Int


Replanting Impact on Emission from Herbicide
Emission from Herbicide(Kg CO2 e)
300000
250000
200000
150000
100000
50000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Emission from Herbicide with no Rep Int
Emission from Herbicide with 100 Ha Rep Int
Emission from Herbicide with 200 Ha Rep Int
Emission from Herbicide with 300 Ha Rep Int
Emission from Herbicide with 400 Ha Rep Int
Emission from Herbicide with 500 Ha Rep Int
Emission from Herbicide with 600 Ha Rep Int
Emission from Herbicide with 700 Ha Rep Int
Emission from Herbicide with 800 Ha Rep Int
Emission from Herbicide with 900 Ha Rep Int
Emission from Herbicide with 1000 Ha Rep Int

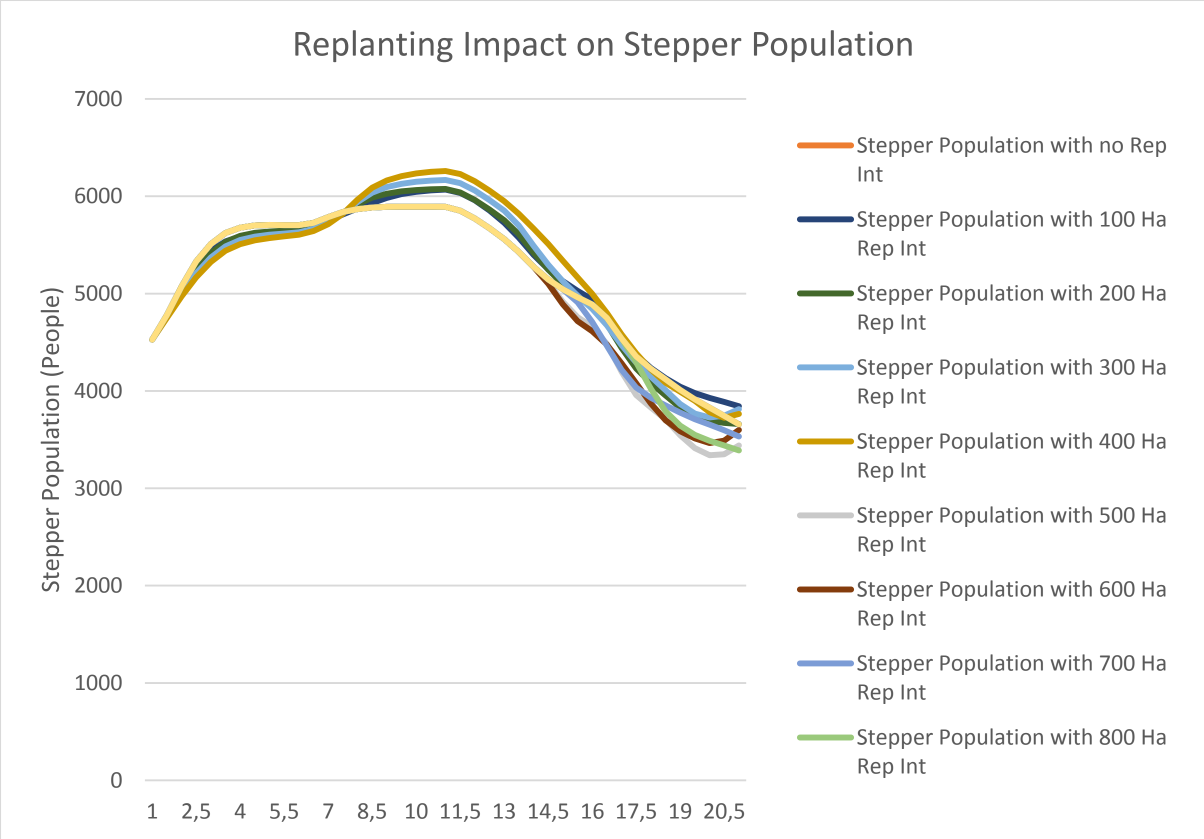

Replanting Impact on Emission of CH4
Emission of CH4 (Kg CH4 e)
60000
50000
40000
30000
20000
10000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
CH4 Emission with no Rep Int
CH4 Emission with 100 Ha Rep Int
CH4 Emission with 200 Ha Rep Int
CH4 Emission with 300 Ha Rep Int
CH4 Emission with 400 Ha Rep Int
CH4 Emission with 500 Ha Rep Int
CH4 Emission with 600 Ha Rep Int
CH4 Emission with 700 Ha Rep Int
CH4 Emission with 800 Ha Rep Int
CH4 Emission with 900 Ha Rep Int
CH4 Emission with 1000 Ha Rep Int

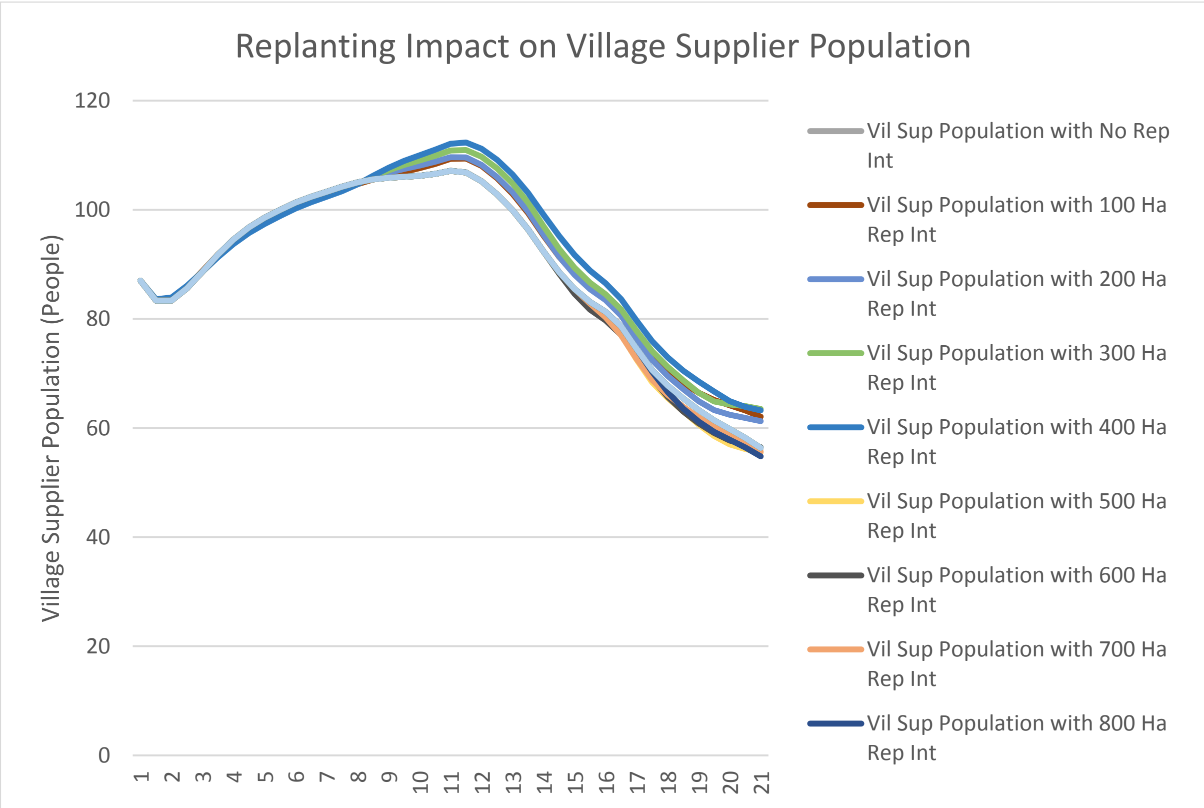


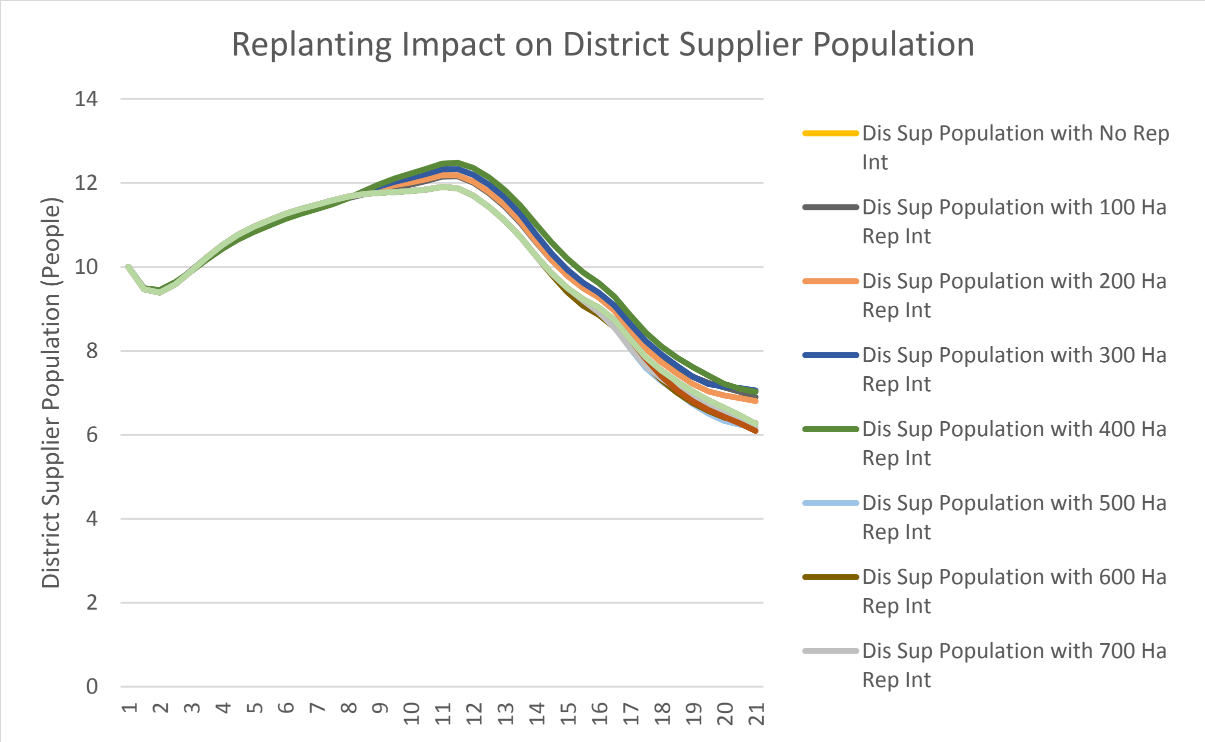
Replanting Impact on Emission of N2O
Emission of N2O (Kg N20 e)
1400
1200
1000
800
600
400
200
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
N2O Emission with no Rep Int
N2O Emission with 100 Ha Rep Int
N2O Emission with 200 Ha Rep Int
N2O Emission with 300 Ha Rep Int
N2O Emission with 400 Ha Rep Int
N2O Emission with 500 Ha Rep Int
N2O Emission with 600 Ha Rep Int
N2O Emission with 700 Ha Rep Int
N2O Emission with 800 Ha Rep Int
N2O Emission with 900 Ha Rep Int
N2O Emission with 1000 Ha Rep Int

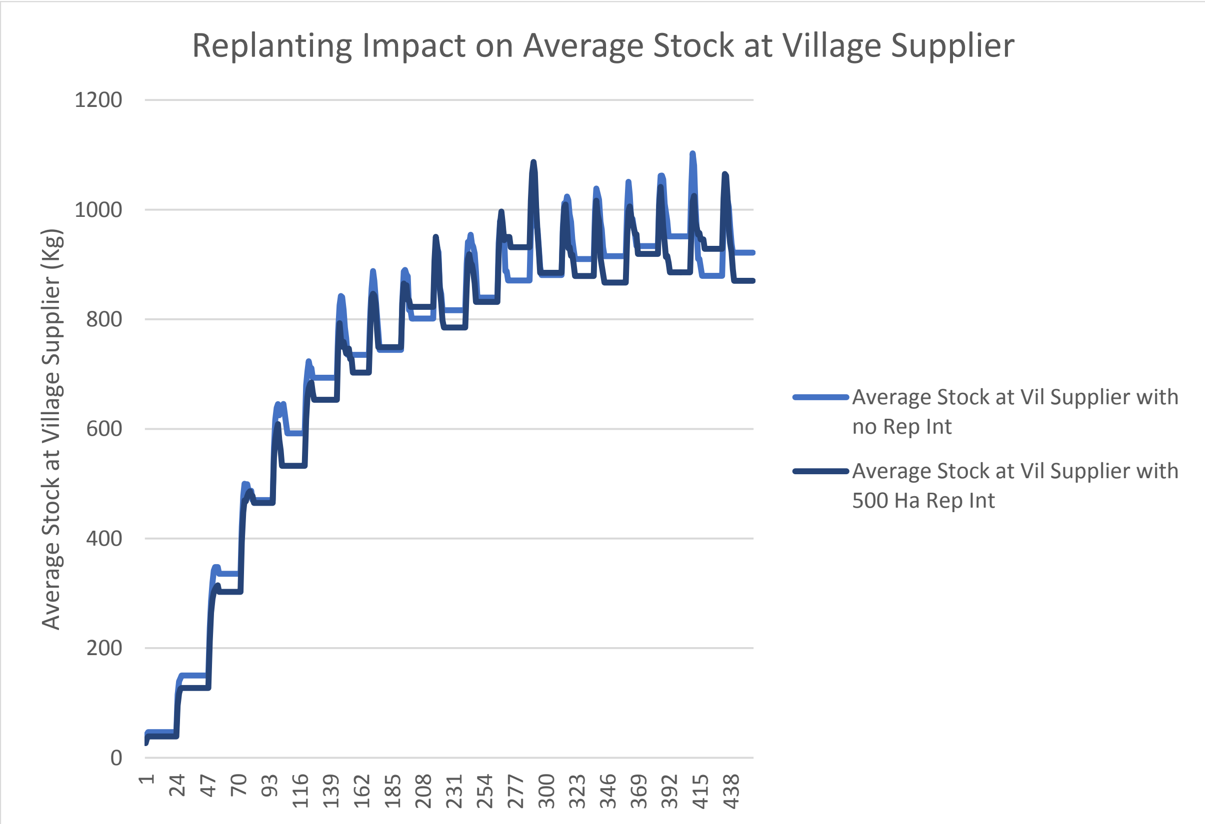


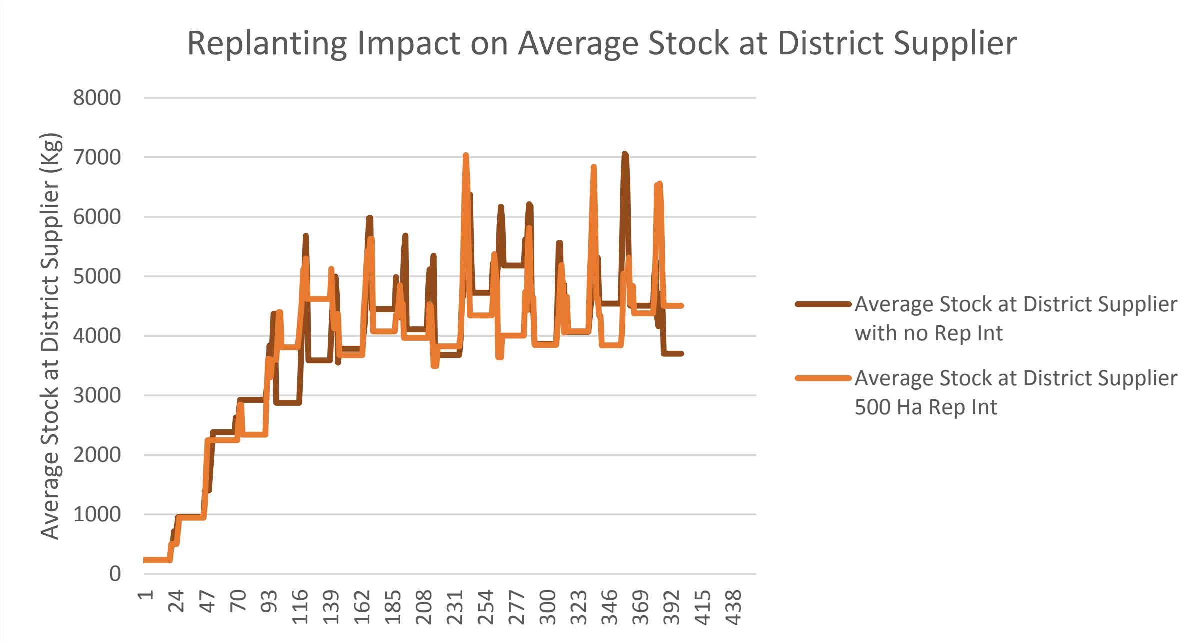
Replanting Impact on Smallholder Population
Smallholder Population (People)
6000
5000
4000
3000
2000
1000
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
Smallholder Population with No Rep Int
Smallholder Population with 100 Ha Rep Int
Smallholder Population with 200 Ha Rep Int
Smallholder Population with 300 Ha Rep Int
Smallholder Population with 400 Ha Rep Int
Smallholder Population with 500 Ha Rep Int
Smallholder Population with 600 Ha Rep Int
Smallholder Population with 700 Ha Rep Int

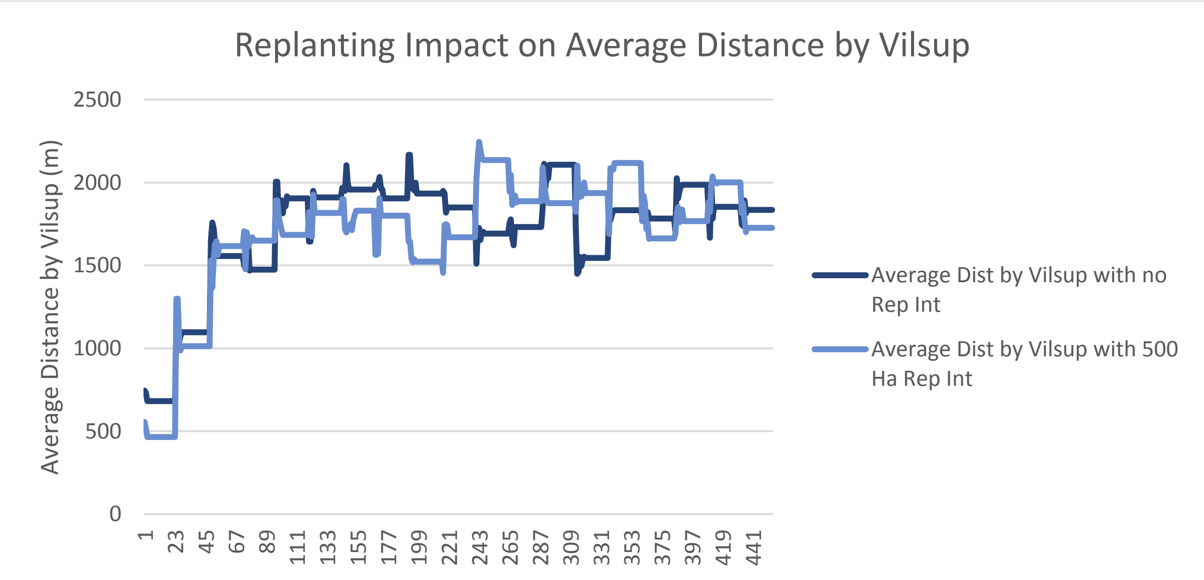

Replanting Impact on Stepper Population
Stepper Population (People)
7000
6000
5000
4000
3000
2000
1000
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
Stepper Population with no Rep Int
Stepper Population with 100 Ha Rep Int
Stepper Population with 200 Ha Rep Int
Stepper Population with 300 Ha Rep Int
Stepper Population with 400 Ha Rep Int
Stepper Population with 500 Ha Rep Int
Stepper Population with 600 Ha Rep Int
Stepper Population with 700 Ha Rep Int
Stepper Population with 800 Ha Rep Int

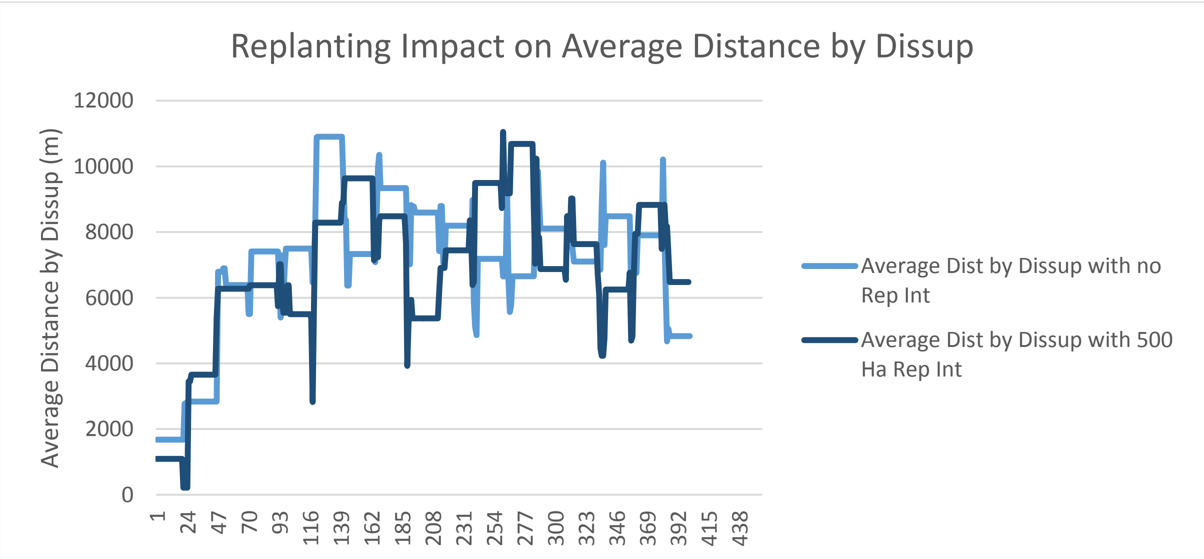

Replanting Impact on Village Supplier Population
Village Supplier Population (People)
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Vil Sup Population with No Rep Int
Vil Sup Population with 100 Ha Rep Int
Vil Sup Population with 200 Ha Rep Int
Vil Sup Population with 300 Ha Rep Int
Vil Sup Population with 400 Ha Rep Int
Vil Sup Population with 500 Ha Rep Int
Vil Sup Population with 600 Ha Rep Int
Vil Sup Population with 700 Ha Rep Int
Vil Sup Population with 800 Ha Rep Int

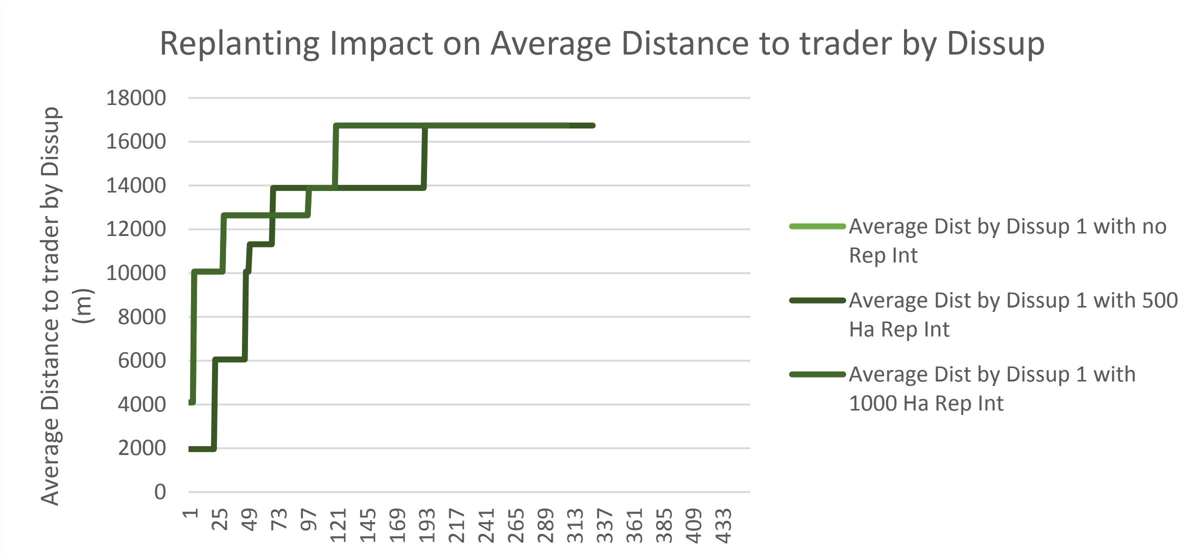

Replanting Impact on District Supplier Population
District Supplier Population (People)
14
12
10
8
6
4
2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Dis Sup Population with No Rep Int
Dis Sup Population with 100 Ha Rep Int
Dis Sup Population with 200 Ha Rep Int
Dis Sup Population with 300 Ha Rep Int
Dis Sup Population with 400 Ha Rep Int
Dis Sup Population with 500 Ha Rep Int
Dis Sup Population with 600 Ha Rep Int
Dis Sup Population with 700 Ha Rep Int


Replanting Impact on Average Stock at Village Supplier
Average Stock at Village Supplier (Kg)
1200
1000
800
600
400
200
0
1 24 47 70 93 116 139 162 185 208 231 254 277 300 323 346 369 392 415 438
Average Stock at Vil Supplier with no Rep Int
Average Stock at Vil Supplier with 500 Ha Rep Int

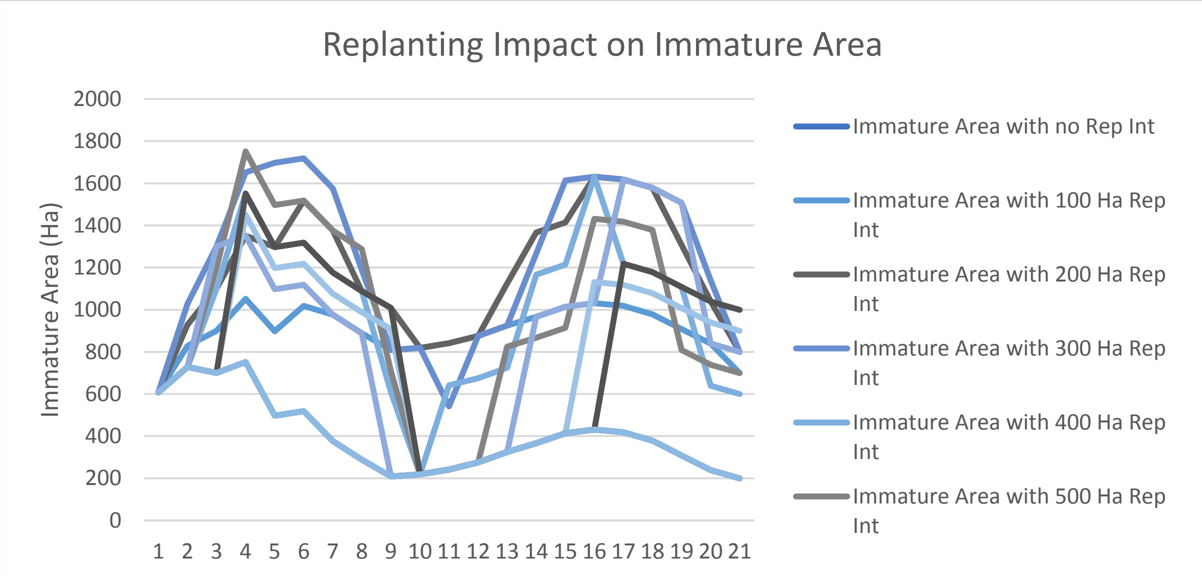

Replanting Impact on Average Stock at District Supplier
Average Stock at District Supplier (Kg)
8000
7000
6000
5000
4000
3000
2000
1000
0
1
24
47
70
93
116
139
162
185
208
231
254
277
300
323
346
369
392
415
438
Average Stock at District Supplier with no Rep Int
Average Stock at District Supplier 500 Ha Rep Int

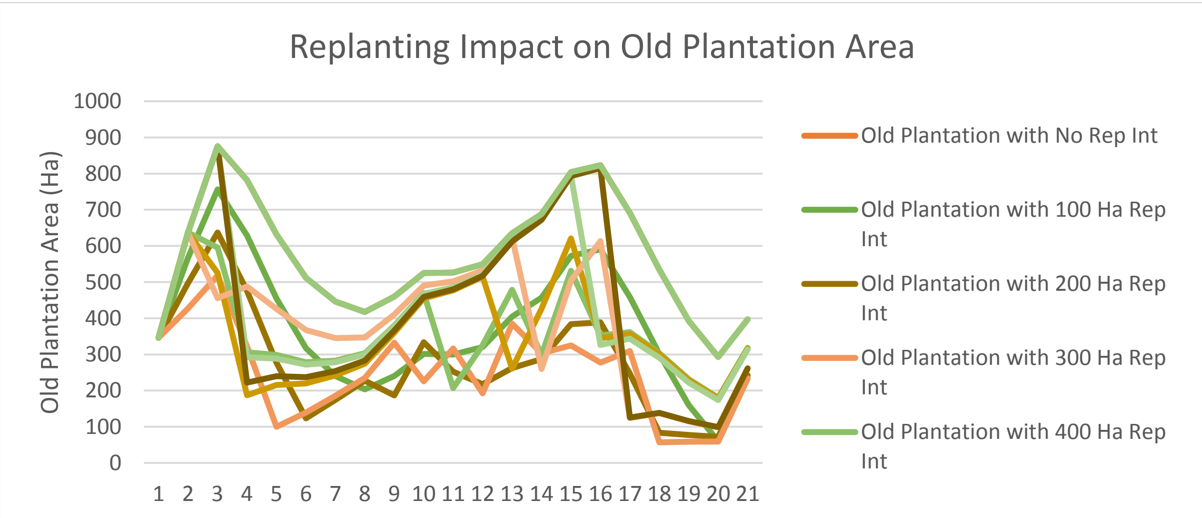

Replanting Impact on Average Distance by Vilsup
Average Distance by Vilsup (m)
2500
2000
1500
1000
500
0
1
23
45
67
89
111
133
155
177
199
221
243
265
287
309
331
353
375
397
419
441
Average Dist by Vilsup with no Rep Int
Average Dist by Vilsup with 500 Ha Rep Int

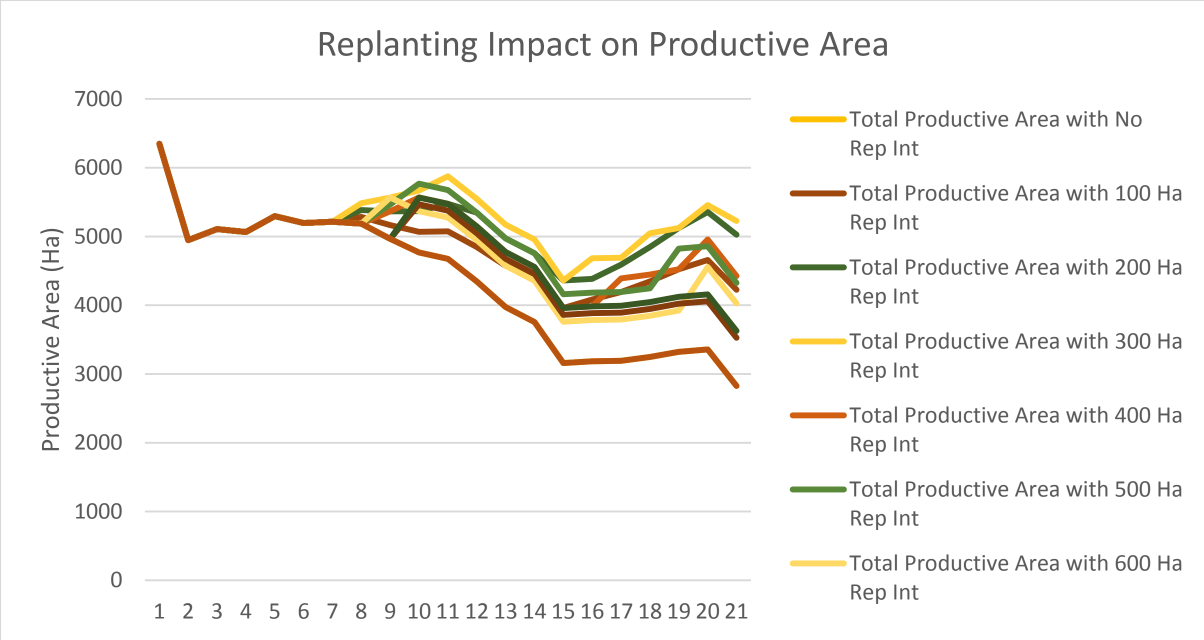

Replanting Impact on Average Distance by Dissup
Average Distance by Dissup (m)
12000
10000
8000
6000
4000
2000
0
1
24
47
70
93
116
139
162
185
208
231
254
277
300
323
346
369
392
415
438
Average Dist by Dissup with no Rep Int
Average Dist by Dissup with 500 Ha Rep Int

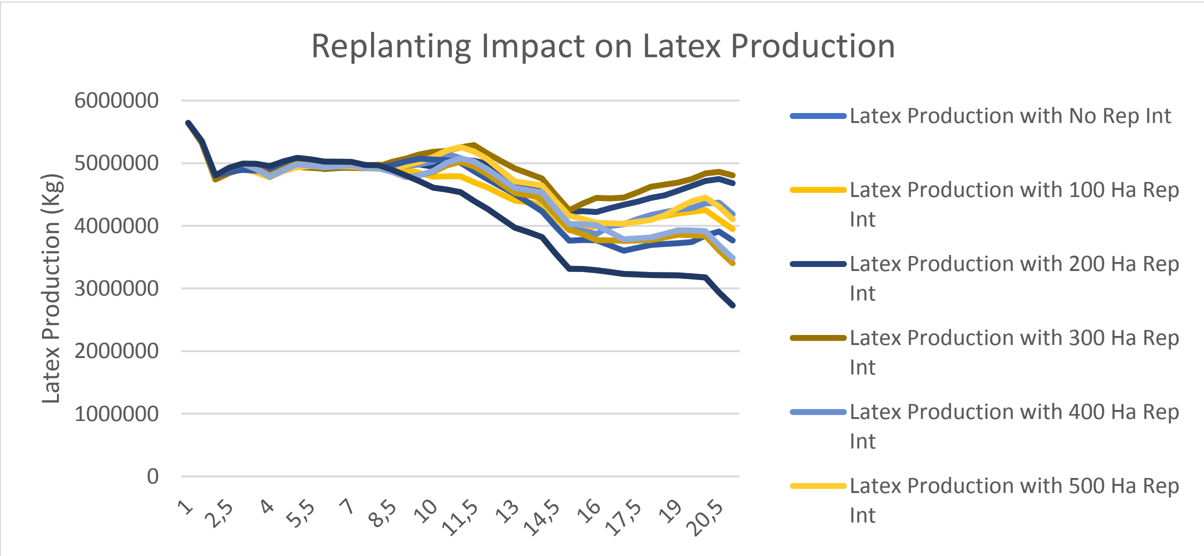


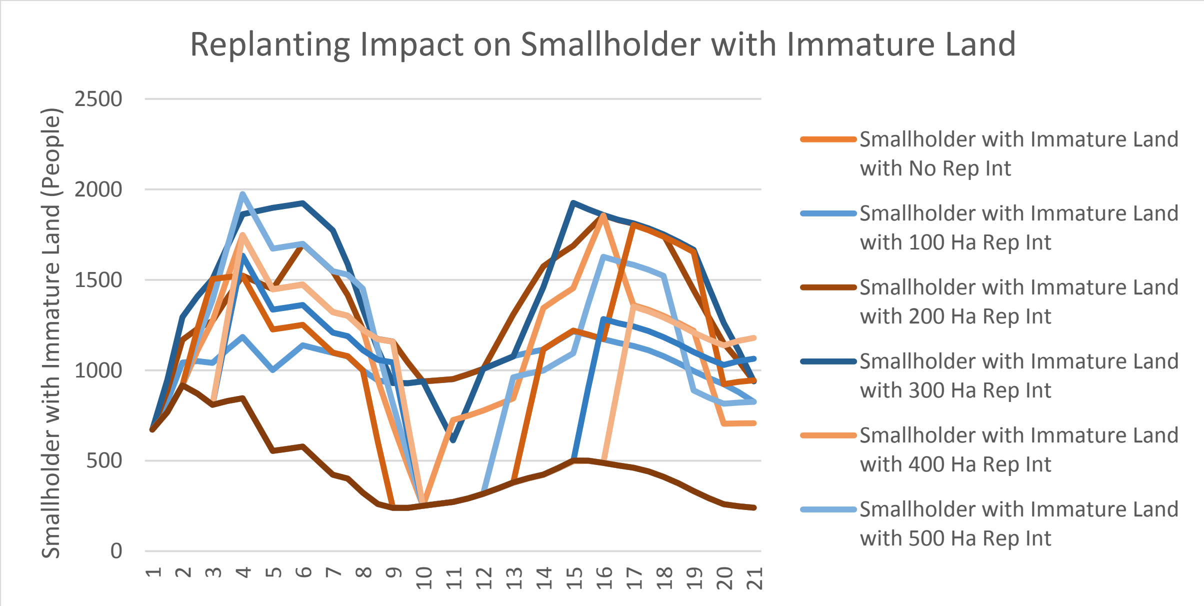
E.2 Simulation Result for Asahan District

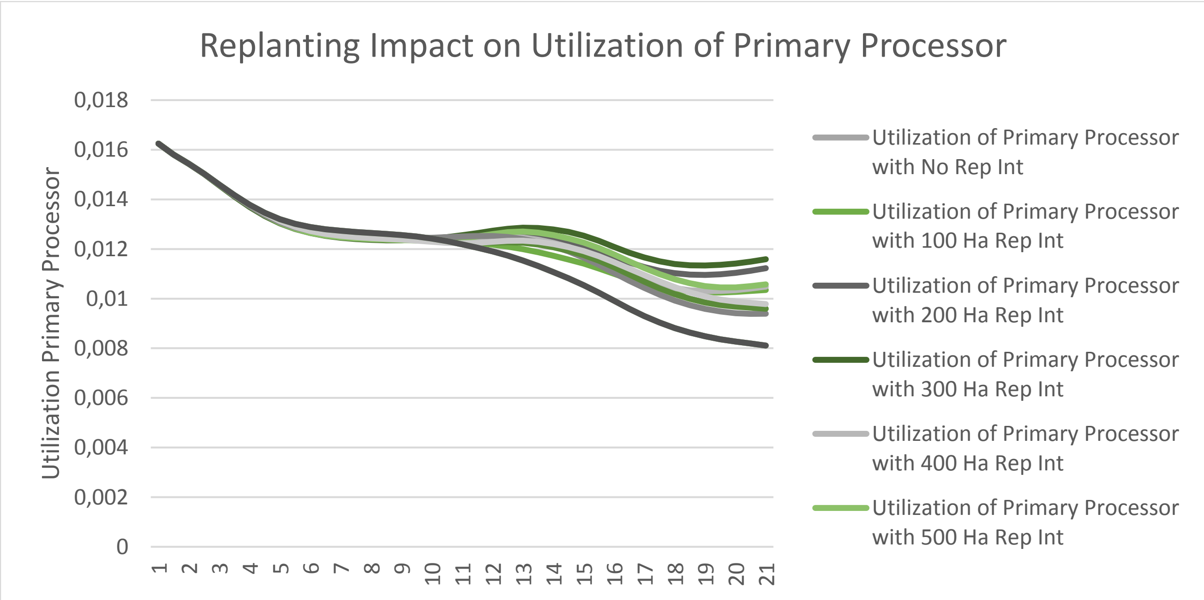


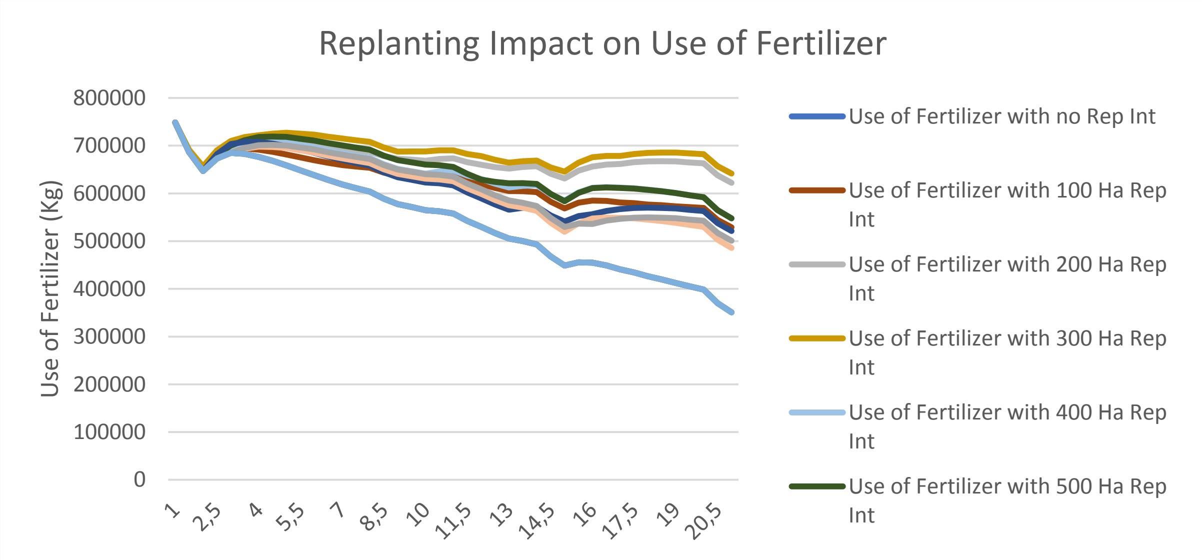


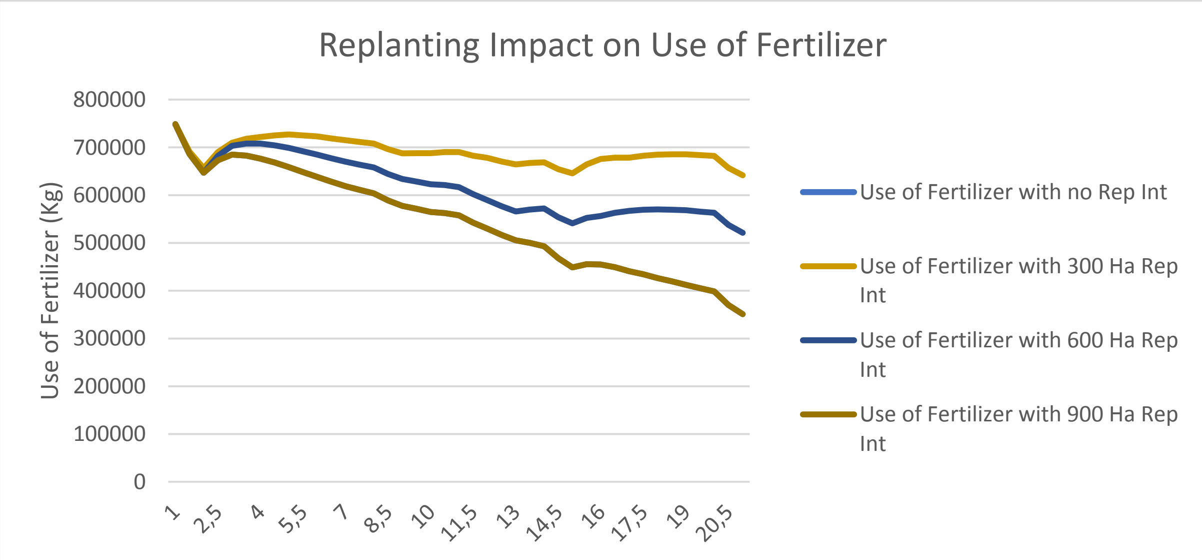

Replanting Impact on Productive Area
Productive Area (Ha)
7000
6000
5000
4000
3000
2000
1000
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Total Productive Area with No Rep Int
Total Productive Area with 100 Ha Rep Int
Total Productive Area with 200 Ha Rep Int
Total Productive Area with 300 Ha Rep Int
Total Productive Area with 400 Ha Rep Int
Total Productive Area with 500 Ha Rep Int
Total Productive Area with 600 Ha Rep Int

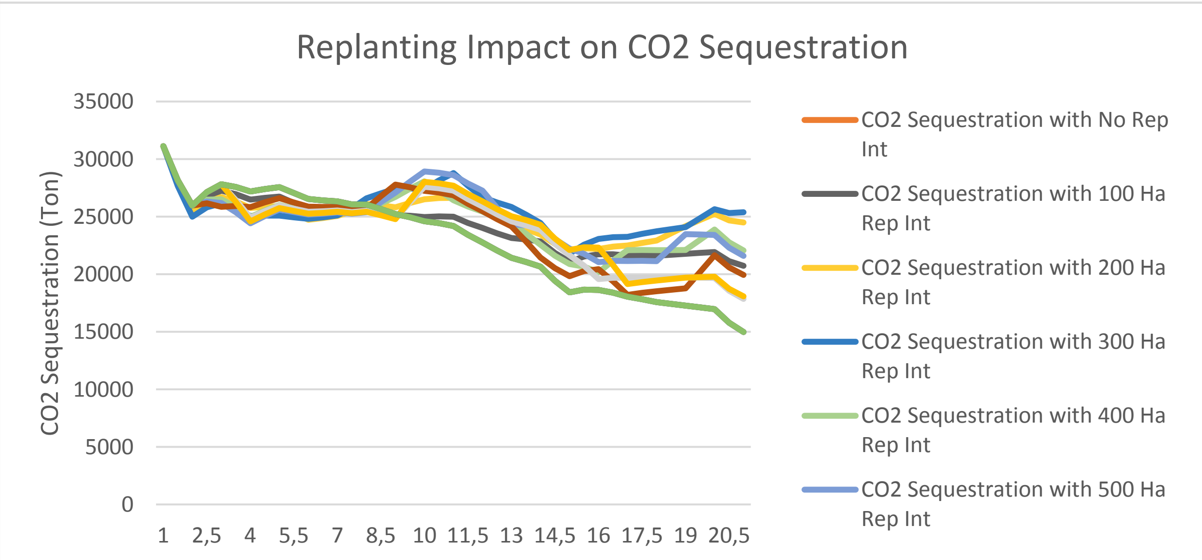

Replanting Impact on Latex Production
Latex Production (Kg)
6000000
5000000
4000000
3000000
2000000
1000000
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
Latex Production with No Rep Int
Latex Production with 100 Ha Rep Int
Latex Production with 200 Ha Rep Int
Latex Production with 300 Ha Rep Int
Latex Production with 400 Ha Rep Int
Latex Production with 500 Ha Rep Int

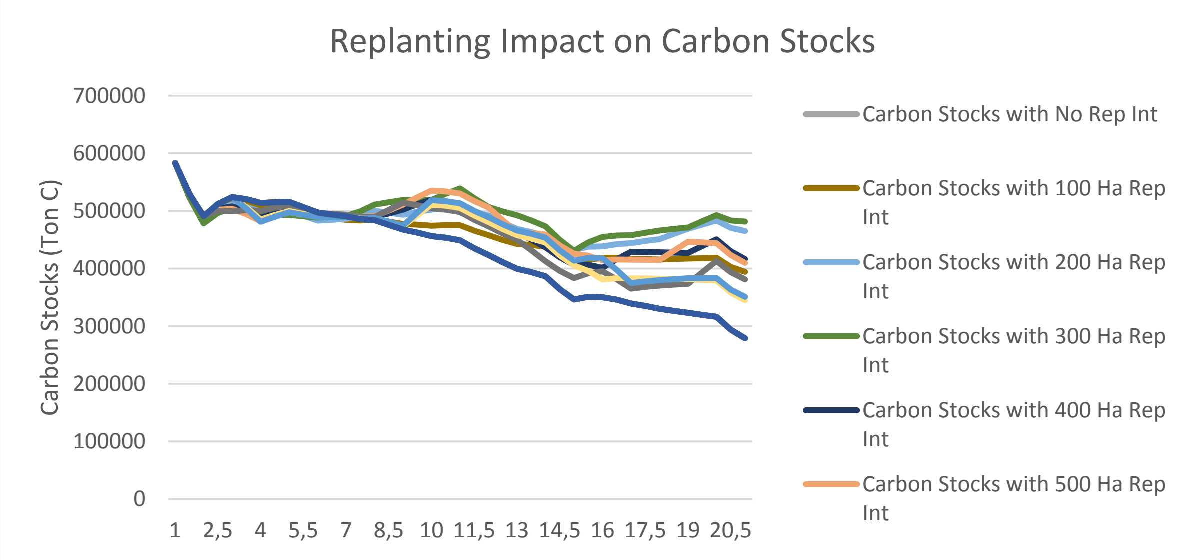

Replanting Impact on Smallholder with Immature Land
Smallholder with Immature Land (People)
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Smallholder with Immature Land with No Rep Int
Smallholder with Immature Land with 100 Ha Rep Int
Smallholder with Immature Land with 200 Ha Rep Int
Smallholder with Immature Land with 300 Ha Rep Int
Smallholder with Immature Land with 400 Ha Rep Int
Smallholder with Immature Land with 500 Ha Rep Int

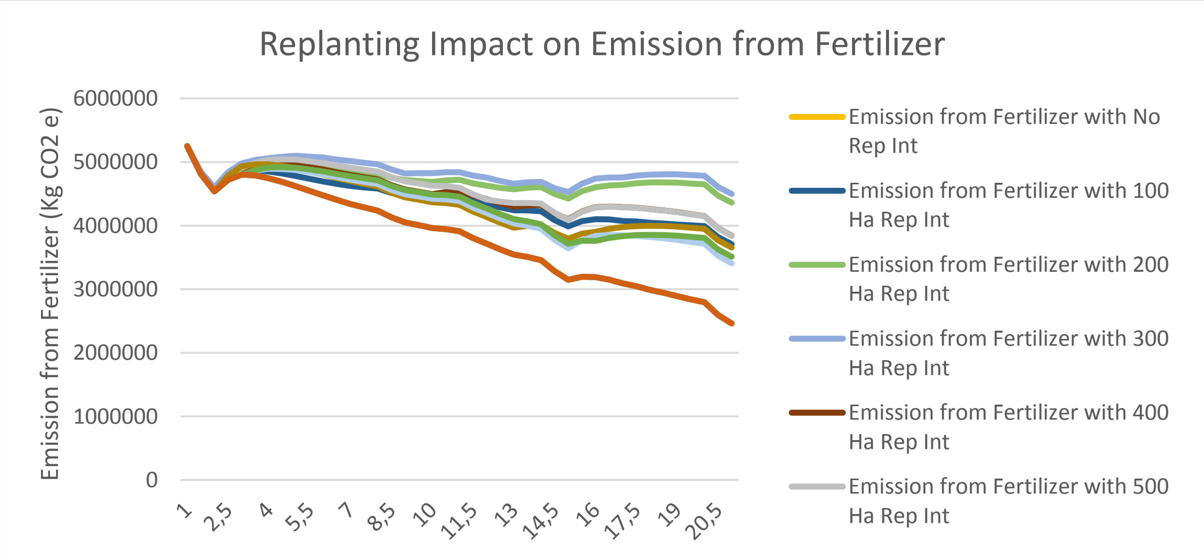

Replanting Impact on Utilization of Primary Processor
Utilization Primary Processor
0,018
0,016
0,014
0,012
0,01
0,008
0,006
0,004
0,002
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Utilization of Primary Processor with No Rep Int
Utilization of Primary Processor with 100 Ha Rep Int
Utilization of Primary Processor with 200 Ha Rep Int
Utilization of Primary Processor with 300 Ha Rep Int
Utilization of Primary Processor with 400 Ha Rep Int
Utilization of Primary Processor with 500 Ha Rep Int

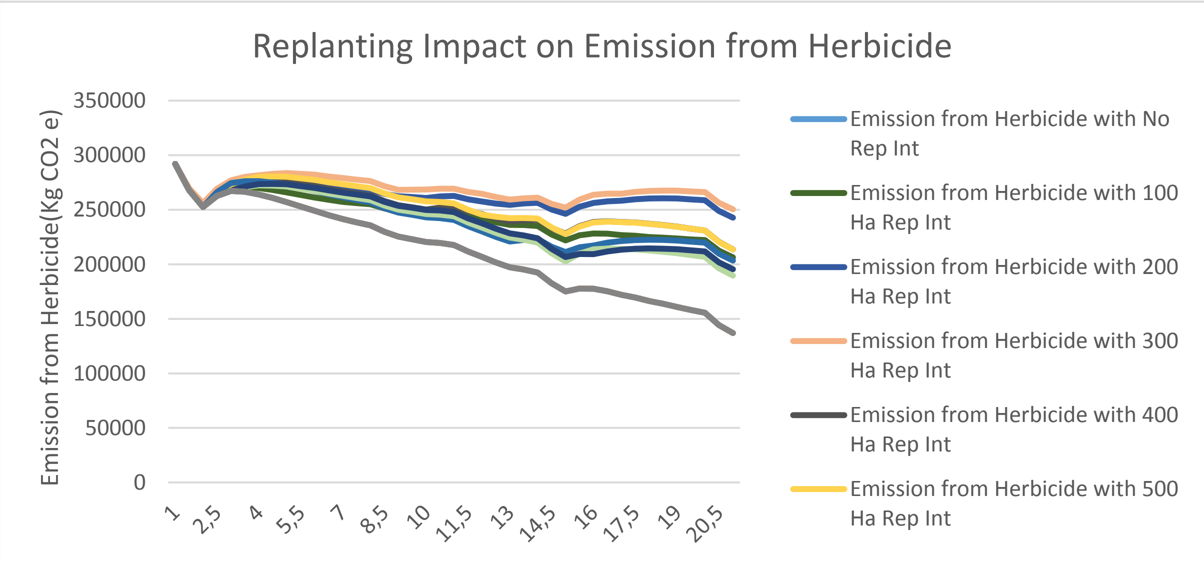

Replanting Impact on Use of Fertilizer
Use of Fertilizer (Kg)
800000
700000
600000
500000
400000
300000
200000
100000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
Use of Fertilizer with no Rep Int
Use of Fertilizer with 100 Ha Rep Int
Use of Fertilizer with 200 Ha Rep Int
Use of Fertilizer with 300 Ha Rep Int
Use of Fertilizer with 400 Ha Rep Int
Use of Fertilizer with 500 Ha Rep Int

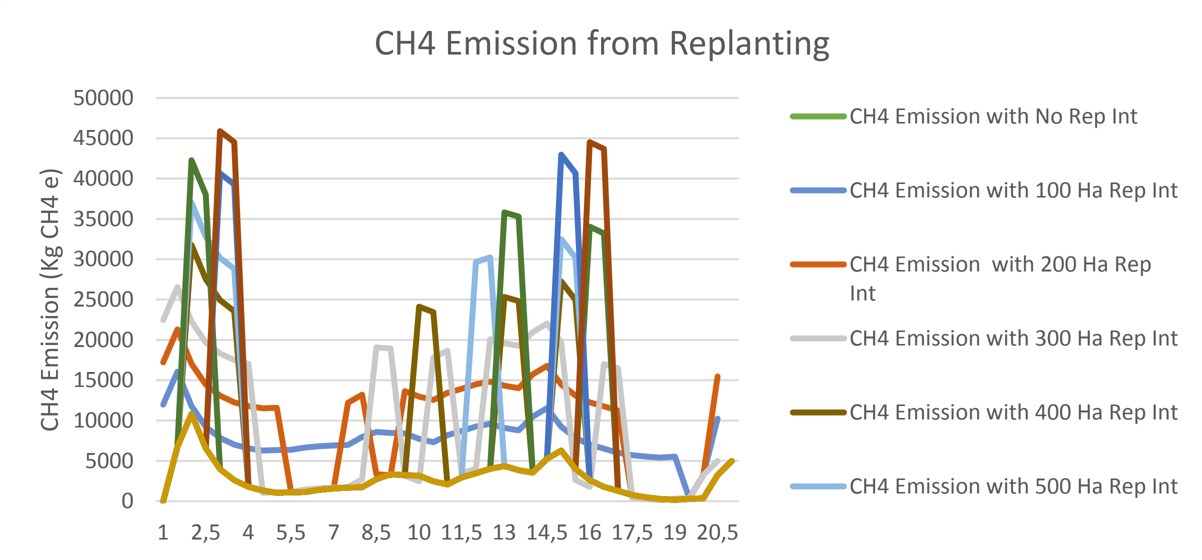

Replanting Impact on Use of Fertilizer
Use of Fertilizer (Kg)
800000
700000
600000
500000
400000
300000
200000
100000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
Use of Fertilizer with no Rep Int
Use of Fertilizer with 300 Ha Rep Int
Use of Fertilizer with 600 Ha Rep Int
Use of Fertilizer with 900 Ha Rep Int

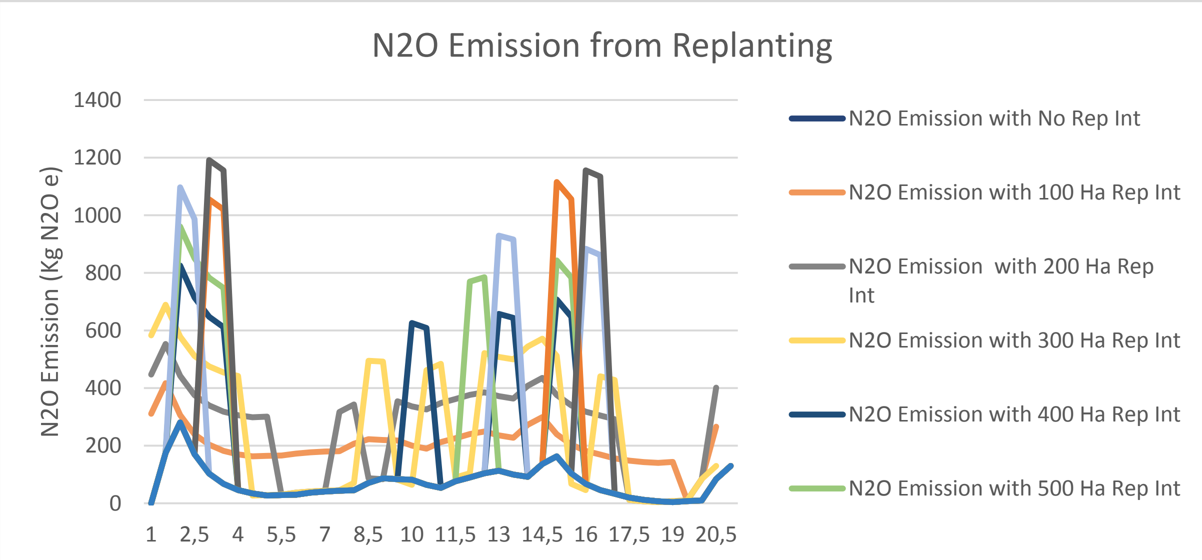

Replanting Impact on CO2 Sequestration
CO2 Sequestration (Ton)
35000
30000
25000
20000
15000
10000
5000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
CO2 Sequestration with No Rep Int
CO2 Sequestration with 100 Ha Rep Int
CO2 Sequestration with 200 Ha Rep Int
CO2 Sequestration with 300 Ha Rep Int
CO2 Sequestration with 400 Ha Rep Int
CO2 Sequestration with 500 Ha Rep Int

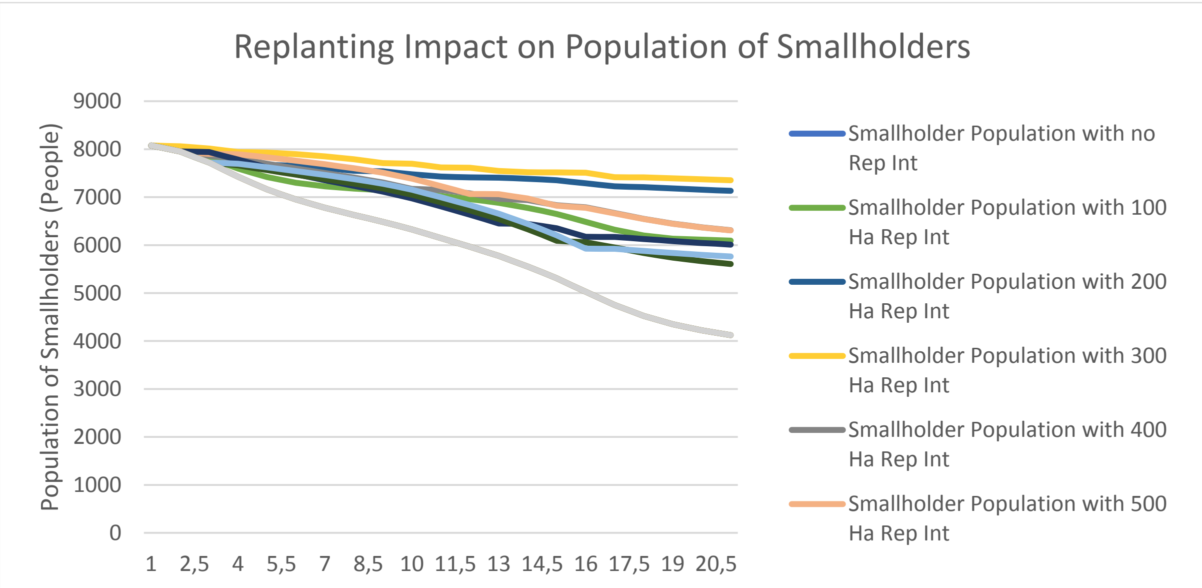

Replanting Impact on Carbon Stocks
Carbon Stocks (Ton C)
700000
600000
500000
400000
300000
200000
100000
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
Carbon Stocks with No Rep Int
Carbon Stocks with 100 Ha Rep Int
Carbon Stocks with 200 Ha Rep Int
Carbon Stocks with 300 Ha Rep Int
Carbon Stocks with 400 Ha Rep Int
Carbon Stocks with 500 Ha Rep Int

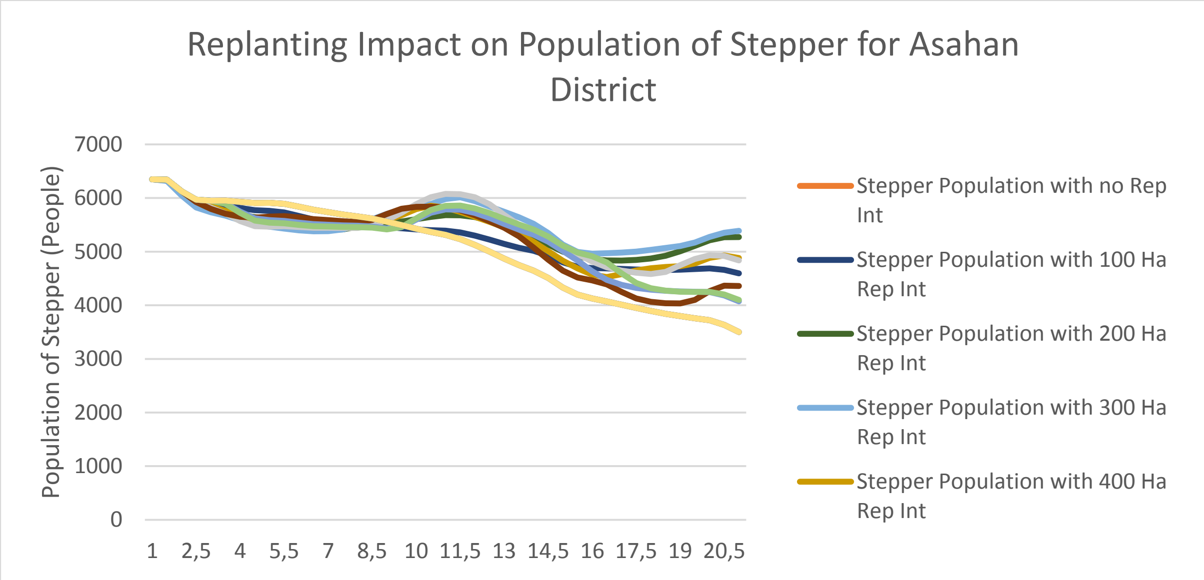

Replanting Impact on Emission from Fertilizer
Emission from Fertilizer (Kg CO2 e)
6000000
5000000
4000000
3000000
2000000
1000000
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
Emission from Fertilizer with No Rep Int
Emission from Fertilizer with 100 Ha Rep Int
Emission from Fertilizer with 200 Ha Rep Int
Emission from Fertilizer with 300 Ha Rep Int
Emission from Fertilizer with 400 Ha Rep Int
Emission from Fertilizer with 500 Ha Rep Int


Replanting Impact on Emission from Herbicide
Emission from Herbicide(Kg CO2 e)
350000
300000
250000
200000
150000
100000
50000
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
Emission from Herbicide with No Rep Int
Emission from Herbicide with 100 Ha Rep Int
Emission from Herbicide with 200 Ha Rep Int
Emission from Herbicide with 300 Ha Rep Int
Emission from Herbicide with 400 Ha Rep Int
Emission from Herbicide with 500 Ha Rep Int

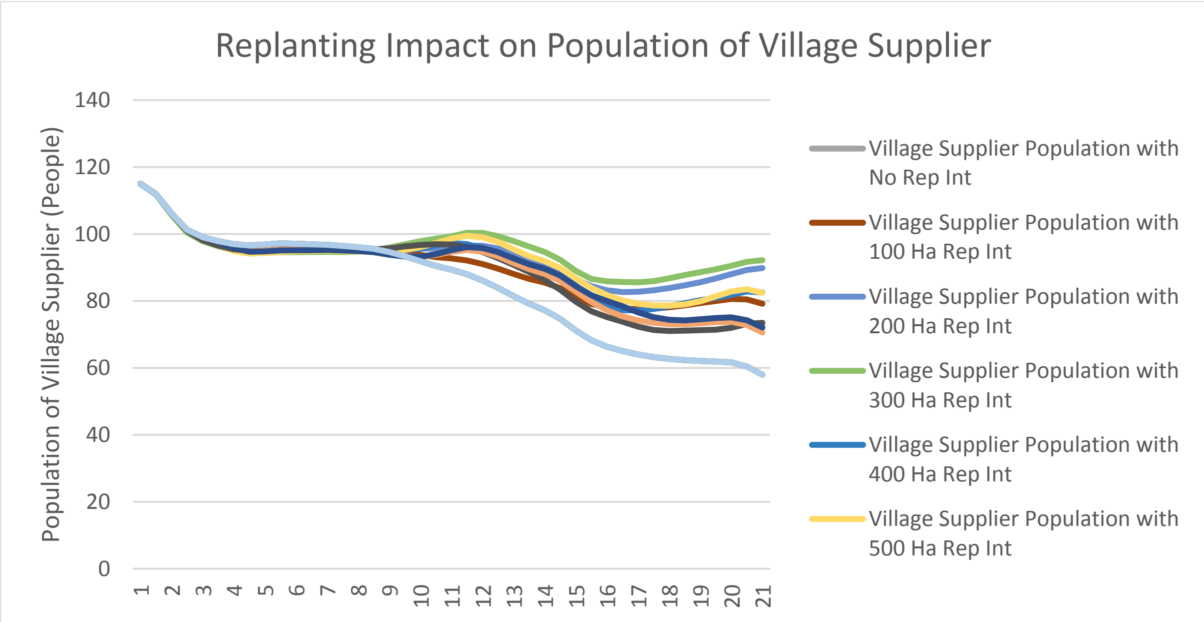

CH4 Emission from Replanting
CH4 Emission (Kg CH4 e)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
CH4 Emission with No Rep Int
CH4 Emission with 100 Ha Rep Int
CH4 Emission with 200 Ha Rep Int
CH4 Emission with 300 Ha Rep Int
CH4 Emission with 400 Ha Rep Int
CH4 Emission with 500 Ha Rep Int


N2O Emission from Replanting
N2O Emission (Kg N2O e)
1400
1200
1000
800
600
400
200
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
N2O Emission with No Rep Int
N2O Emission with 100 Ha Rep Int
N2O Emission with 200 Ha Rep Int
N2O Emission with 300 Ha Rep Int
N2O Emission with 400 Ha Rep Int
N2O Emission with 500 Ha Rep Int

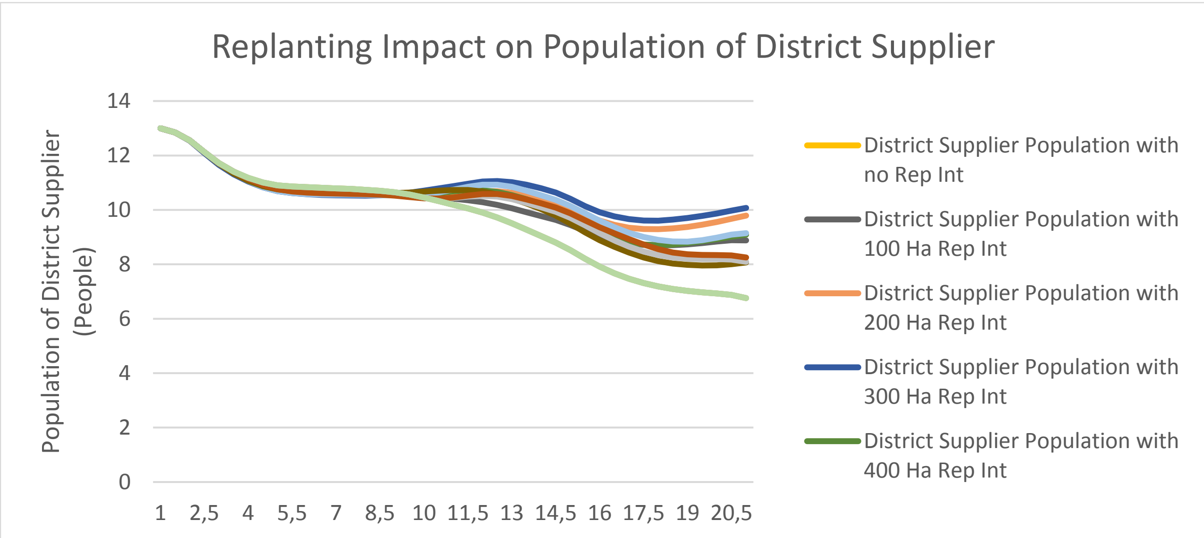

Replanting Impact on Population of Smallholders
Population of Smallholders (People)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
Smallholder Population with no Rep Int
Smallholder Population with 100 Ha Rep Int
Smallholder Population with 200 Ha Rep Int
Smallholder Population with 300 Ha Rep Int
Smallholder Population with 400 Ha Rep Int
Smallholder Population with 500 Ha Rep Int



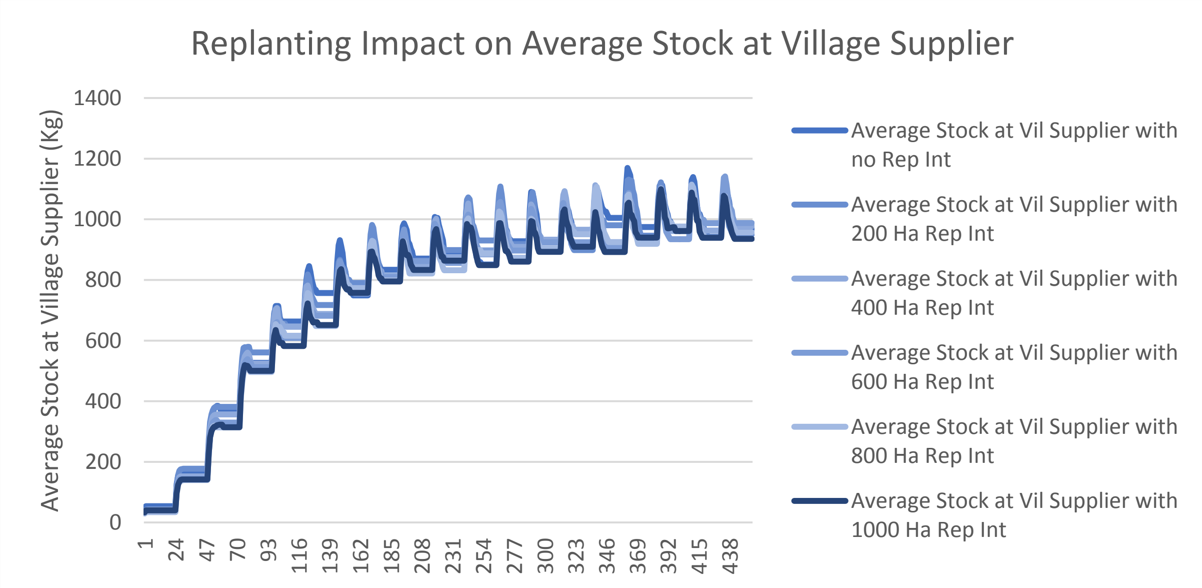
Replanting Impact on Population of Stepper for Asahan District
Population of Stepper (People)
7000
6000
5000
4000
3000
2000
1000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
Stepper Population with no Rep Int
Stepper Population with 100 Ha Rep Int
Stepper Population with 200 Ha Rep Int
Stepper Population with 300 Ha Rep Int
Stepper Population with 400 Ha Rep Int



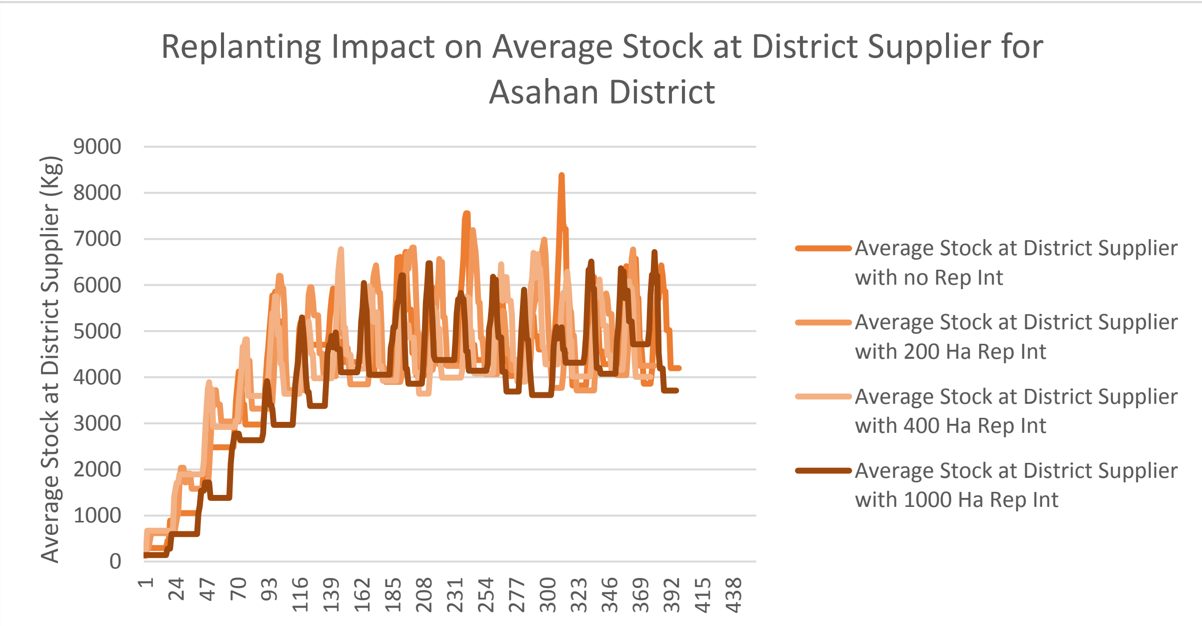
Replanting Impact on Population of Village Supplier
Population of Village Supplier (People)
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Village Supplier Population with No Rep Int
Village Supplier Population with 100 Ha Rep Int
Village Supplier Population with 200 Ha Rep Int
Village Supplier Population with 300 Ha Rep Int
Village Supplier Population with 400 Ha Rep Int
Village Supplier Population with 500 Ha Rep Int



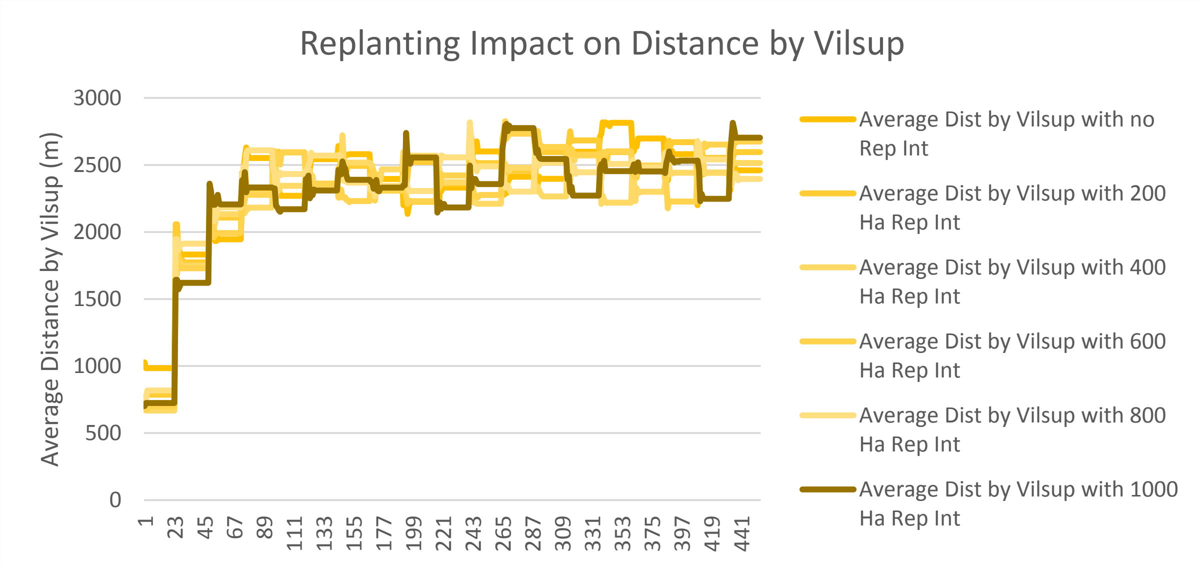
Replanting Impact on Population of District Supplier
Population of District Supplier (People)
14
12
10
8
6
4
2
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
District Supplier Population with no Rep Int
District Supplier Population with 100 Ha Rep Int
District Supplier Population with 200 Ha Rep Int
District Supplier Population with 300 Ha Rep Int
District Supplier Population with 400 Ha Rep Int

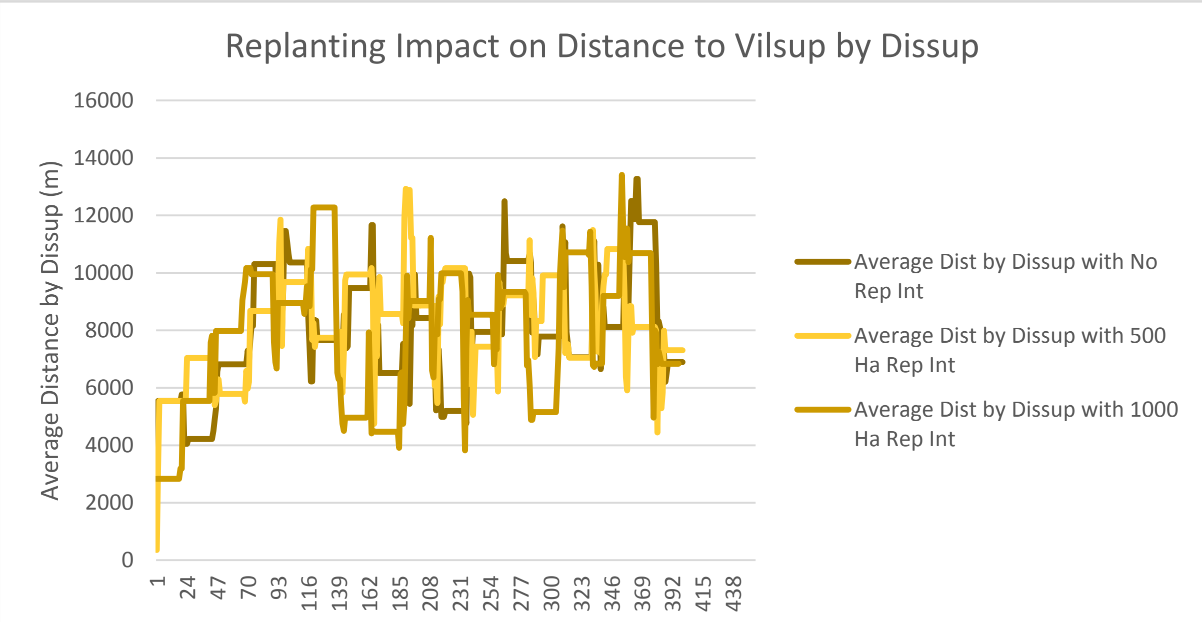


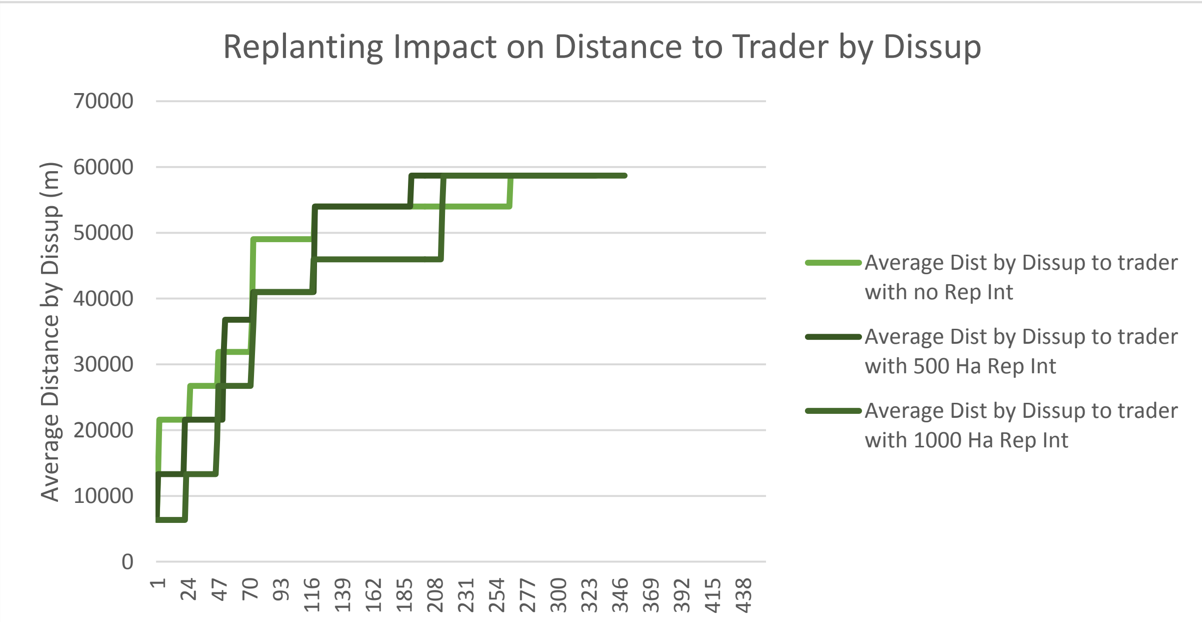
Replanting Impact on Average Stock at Village Supplier
Average Stock at Village Supplier (Kg)
1400
1200
1000
800
600
400
200
0
1
24
47
70
93
116
139
162
185
208
231
254
277
300
323
346
369
392
415
438
Average Stock at Vil Supplier with no Rep Int
Average Stock at Vil Supplier with 200 Ha Rep Int
Average Stock at Vil Supplier with 400 Ha Rep Int
Average Stock at Vil Supplier with 600 Ha Rep Int
Average Stock at Vil Supplier with 800 Ha Rep Int
Average Stock at Vil Supplier with 1000 Ha Rep Int



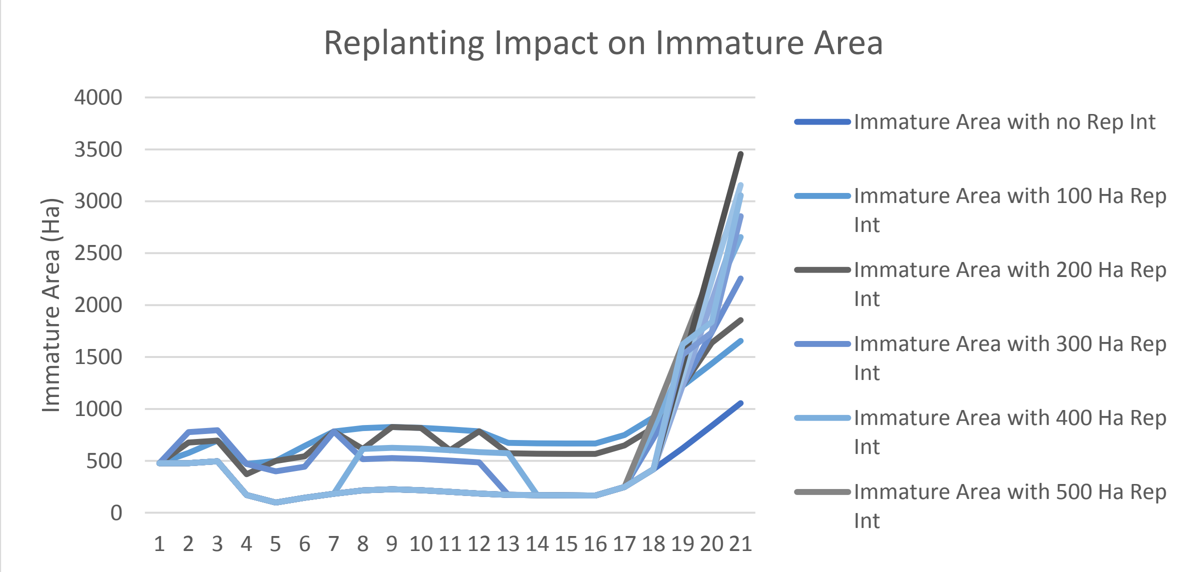
Replanting Impact on Average Stock at District Supplier for Asahan District
Average Stock at District Supplier (Kg)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1
24
47
70
93
116
139
162
185
208
231
254
277
300
323
346
369
392
415
438
Average Stock at District Supplier with no Rep Int
Average Stock at District Supplier with 200 Ha Rep Int
Average Stock at District Supplier with 400 Ha Rep Int
Average Stock at District Supplier with 1000 Ha Rep Int

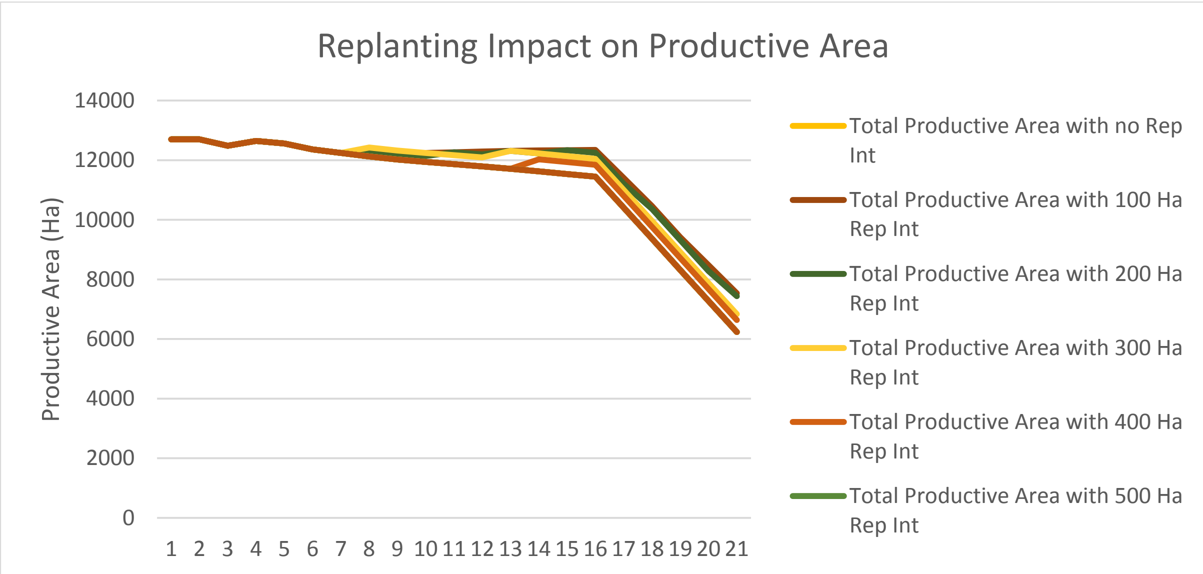

Replanting Impact on Distance by Vilsup
Average Distance by Vilsup (m)
3000
2500
2000
1500
1000
500
0
1
23
45
67
89
111
133
155
177
199
221
243
265
287
309
331
353
375
397
419
441
Average Dist by Vilsup with no Rep Int
Average Dist by Vilsup with 200 Ha Rep Int
Average Dist by Vilsup with 400 Ha Rep Int
Average Dist by Vilsup with 600 Ha Rep Int
Average Dist by Vilsup with 800 Ha Rep Int
Average Dist by Vilsup with 1000 Ha Rep Int

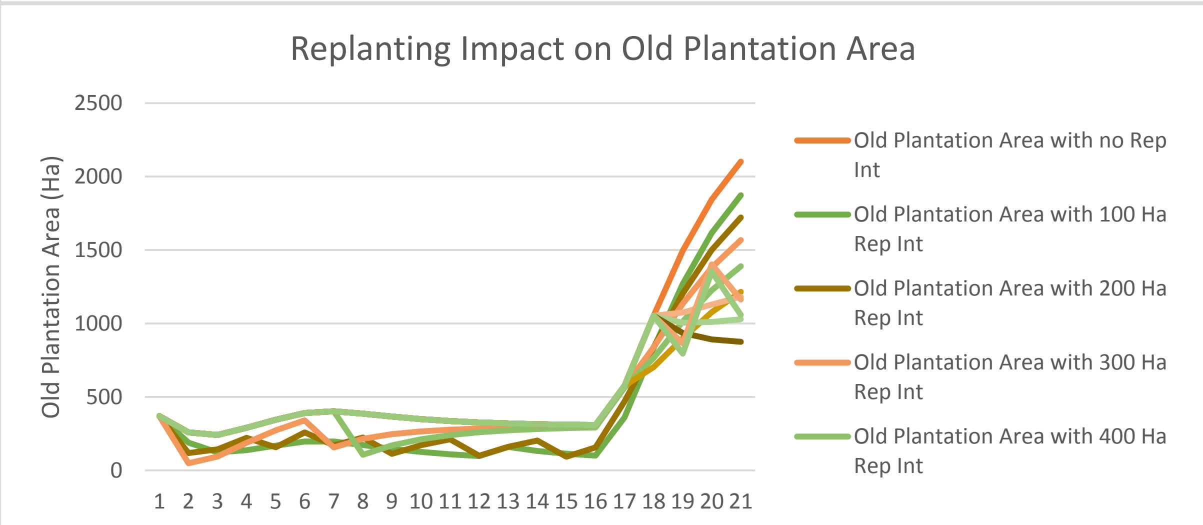

Replanting Impact on Distance to Vilsup by Dissup
Average Distance by Dissup (m)
16000
14000
12000
10000
8000
6000
4000
2000
0
1
24
47
70
93
116
139
162
185
208
231
254
277
300
323
346
369
392
415
438
Average Dist by Dissup with No Rep Int
Average Dist by Dissup with 500 Ha Rep Int
Average Dist by Dissup with 1000 Ha Rep Int

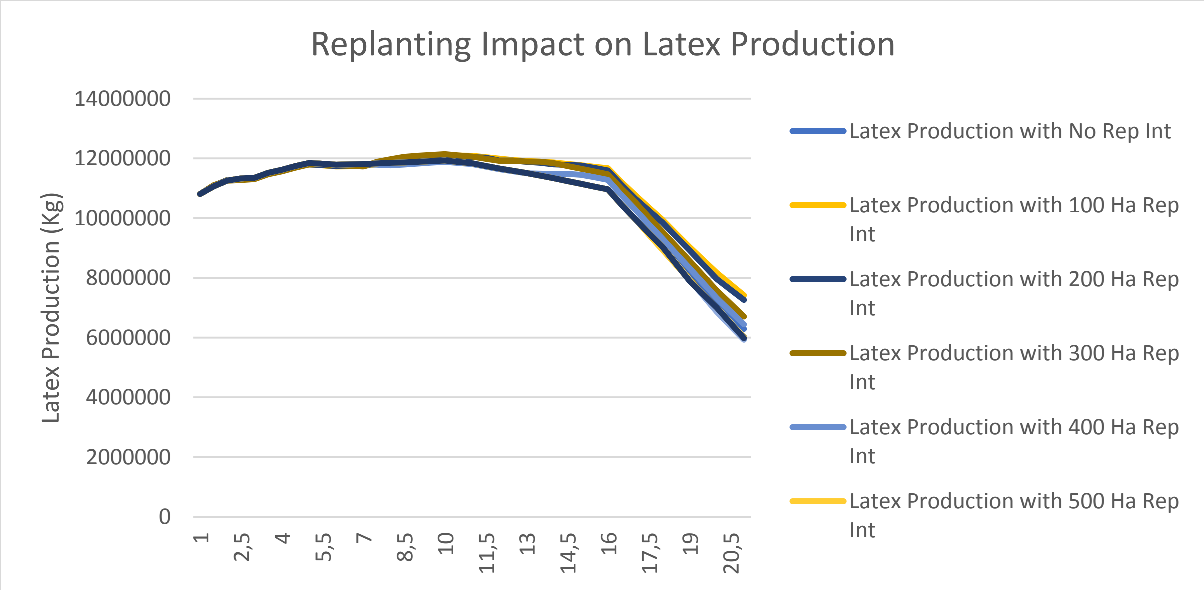

Replanting Impact on Distance to Trader by Dissup
Average Distance by Dissup (m)
70000
60000
50000
40000
30000
20000
10000
0
1
24
47
70
93
116
139
162
185
208
231
254
277
300
323
346
369
392
415
438
Average Dist by Dissup to trader with no Rep Int
Average Dist by Dissup to trader with 500 Ha Rep Int
Average Dist by Dissup to trader with 1000 Ha Rep Int

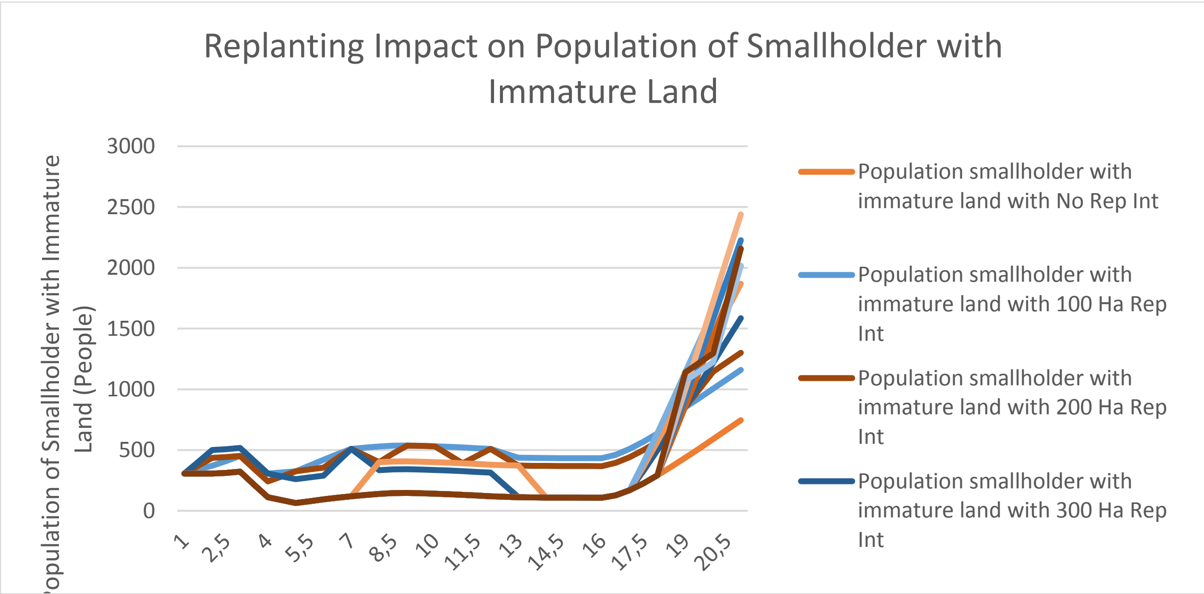
E.3 Simulation Result for Simalungun District

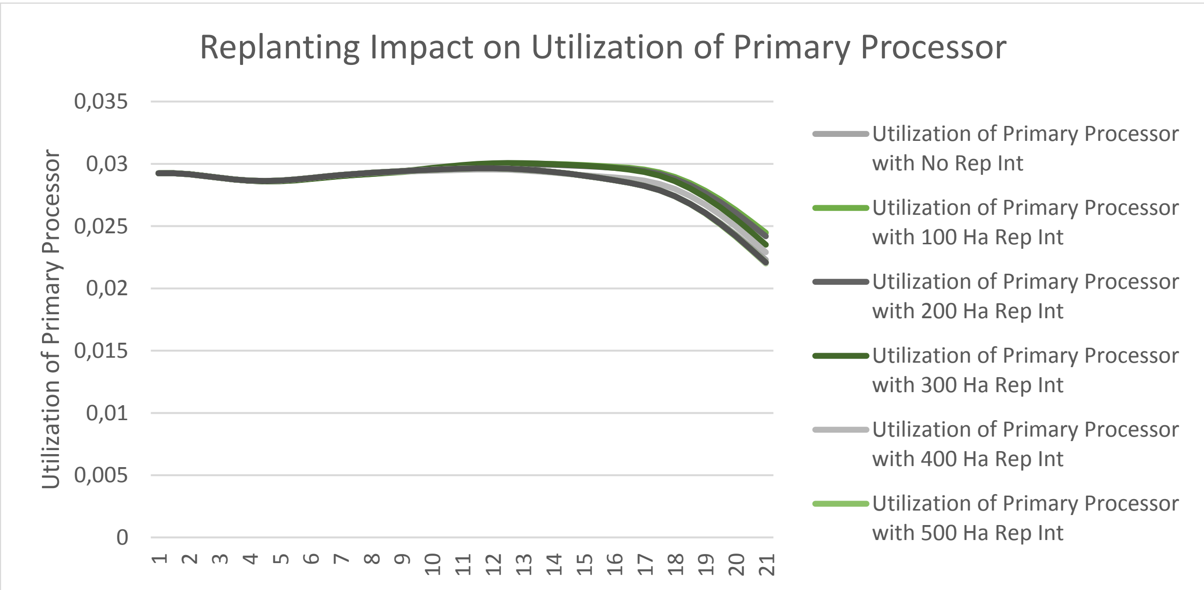


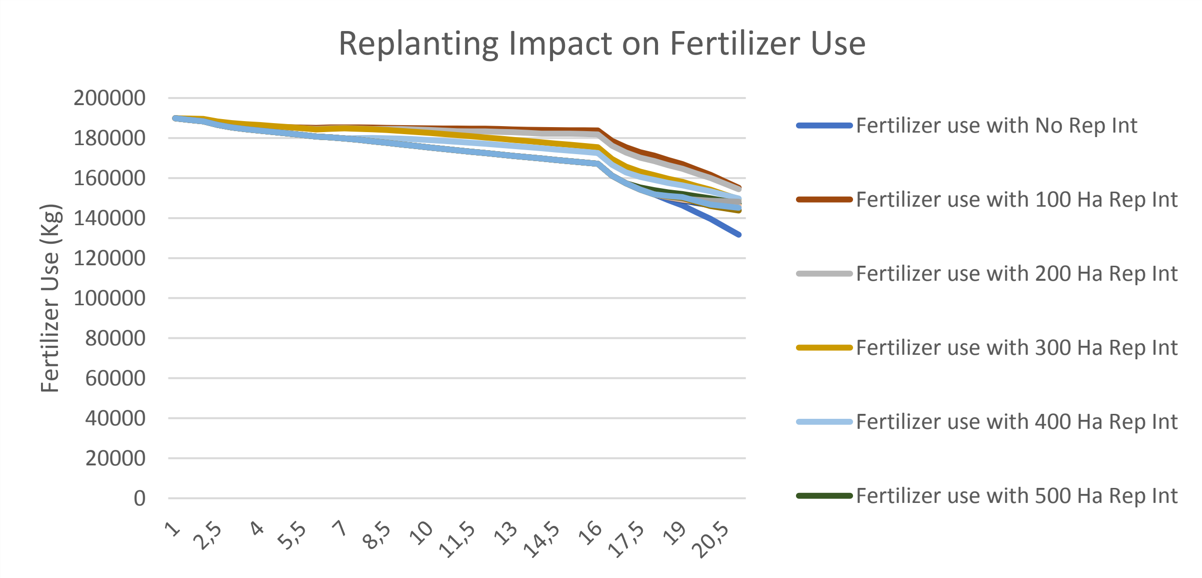


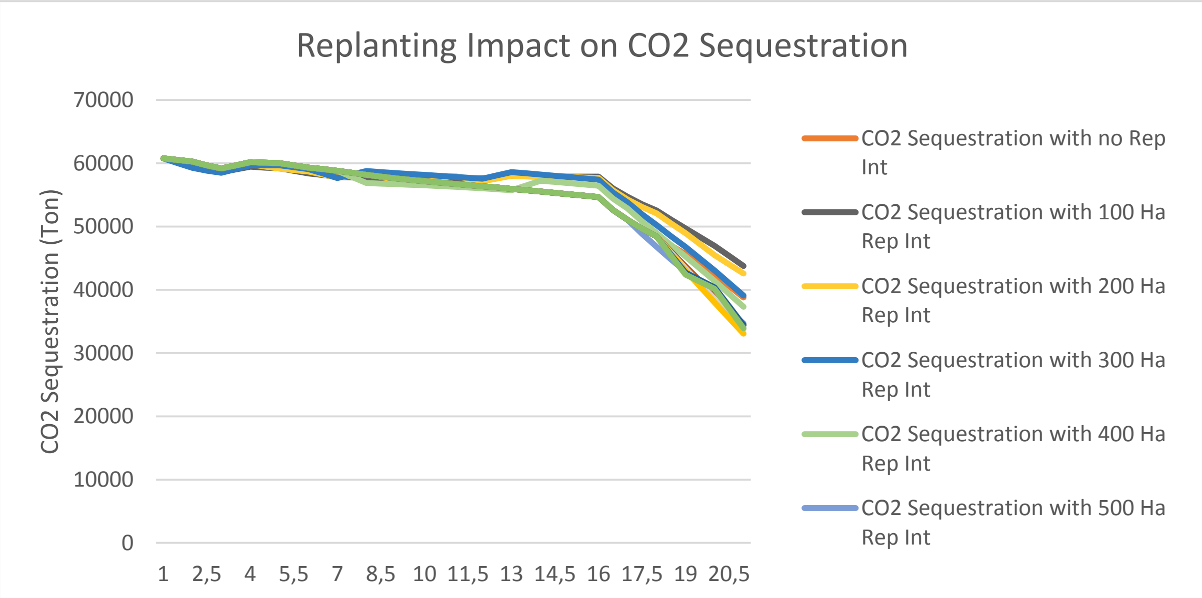


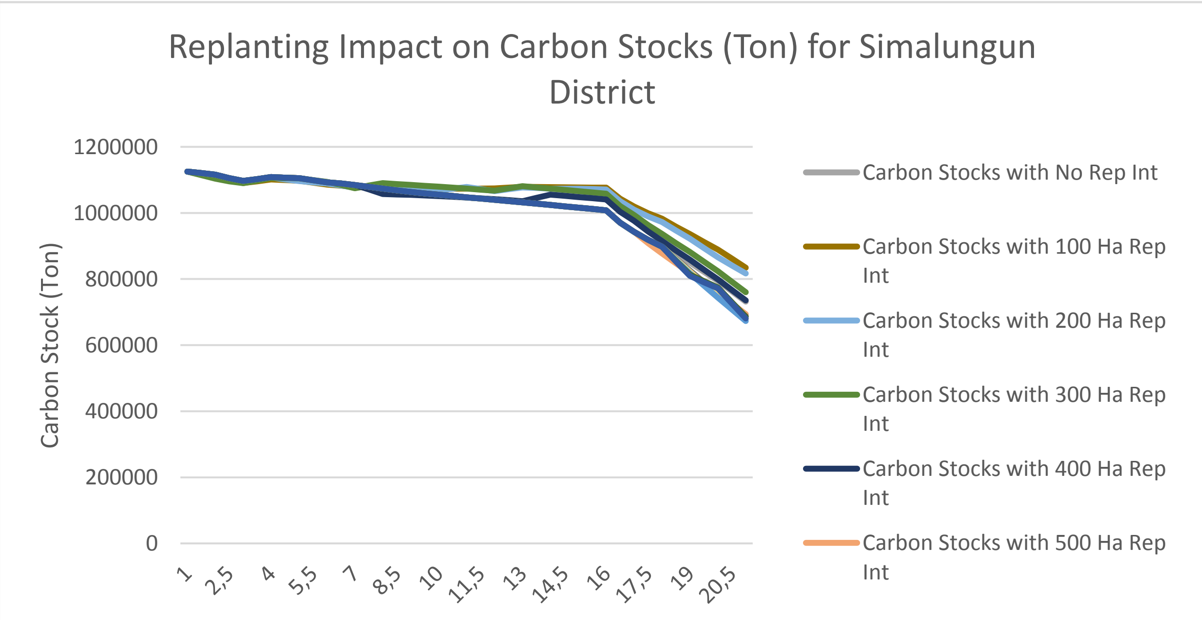

Replanting Impact on Latex Production
Latex Production (Kg)
14000000
12000000
10000000
8000000
6000000
4000000
2000000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
Latex Production with No Rep Int
Latex Production with 100 Ha Rep Int
Latex Production with 200 Ha Rep Int
Latex Production with 300 Ha Rep Int
Latex Production with 400 Ha Rep Int
Latex Production with 500 Ha Rep Int

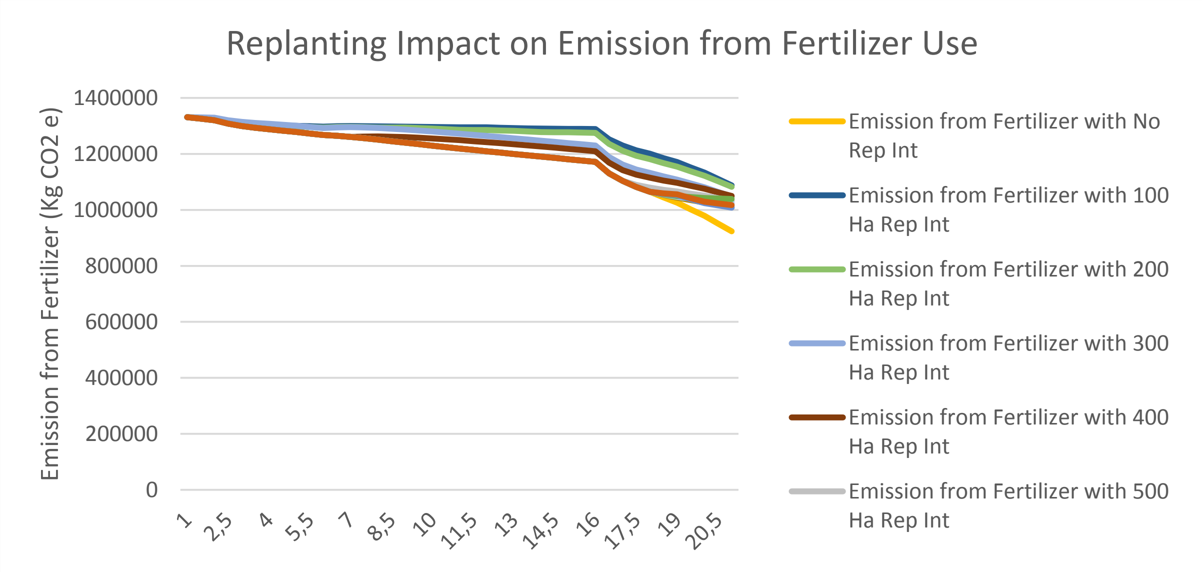

Replanting Impact on Population of Smallholder with Immature Land
opulation of Smallholder with Immature Land (People)
3000
2500
2000
1500
1000
500
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
Population smallholder with immature land with No Rep Int
Population smallholder with immature land with 100 Ha Rep Int
Population smallholder with immature land with 200 Ha Rep Int
Population smallholder with immature land with 300 Ha Rep Int

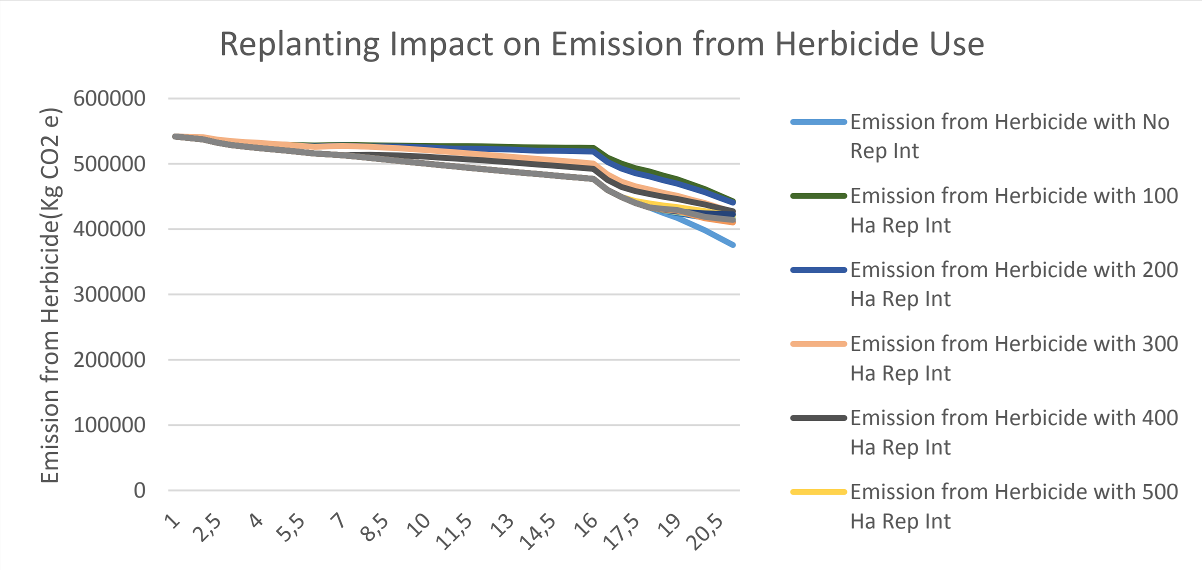

Replanting Impact on Utilization of Primary Processor
Utilization of Primary Processor
0,035
0,03
0,025
0,02
0,015
0,01
0,005
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Utilization of Primary Processor with No Rep Int
Utilization of Primary Processor with 100 Ha Rep Int
Utilization of Primary Processor with 200 Ha Rep Int
Utilization of Primary Processor with 300 Ha Rep Int
Utilization of Primary Processor with 400 Ha Rep Int
Utilization of Primary Processor with 500 Ha Rep Int

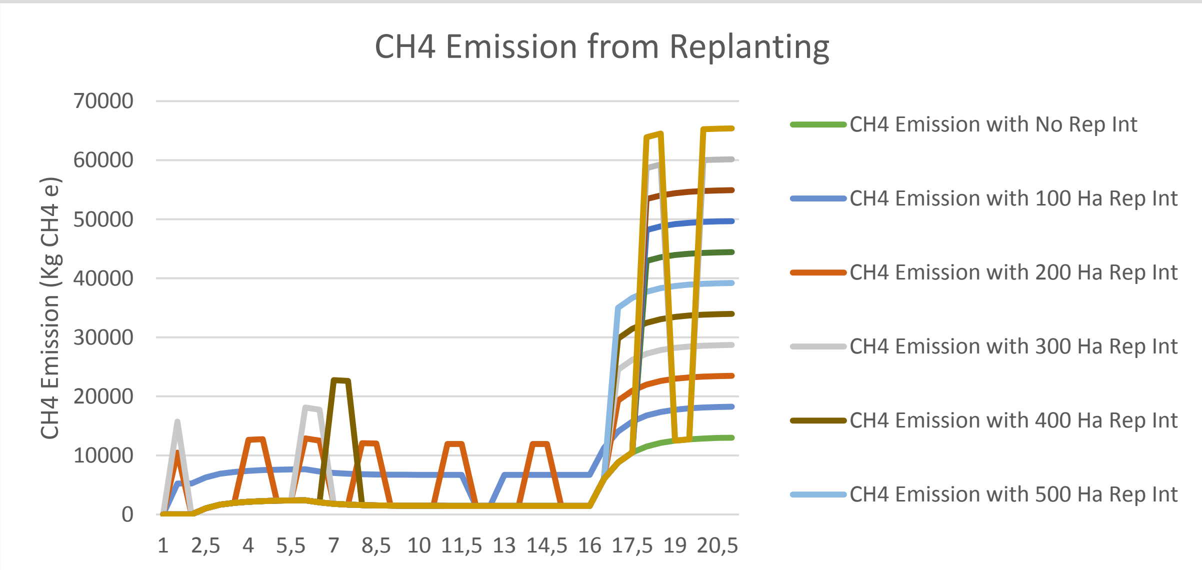

Replanting Impact on Fertilizer Use
Fertilizer Use (Kg)
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
Fertilizer use with No Rep Int
Fertilizer use with 100 Ha Rep Int
Fertilizer use with 200 Ha Rep Int
Fertilizer use with 300 Ha Rep Int
Fertilizer use with 400 Ha Rep Int
Fertilizer use with 500 Ha Rep Int

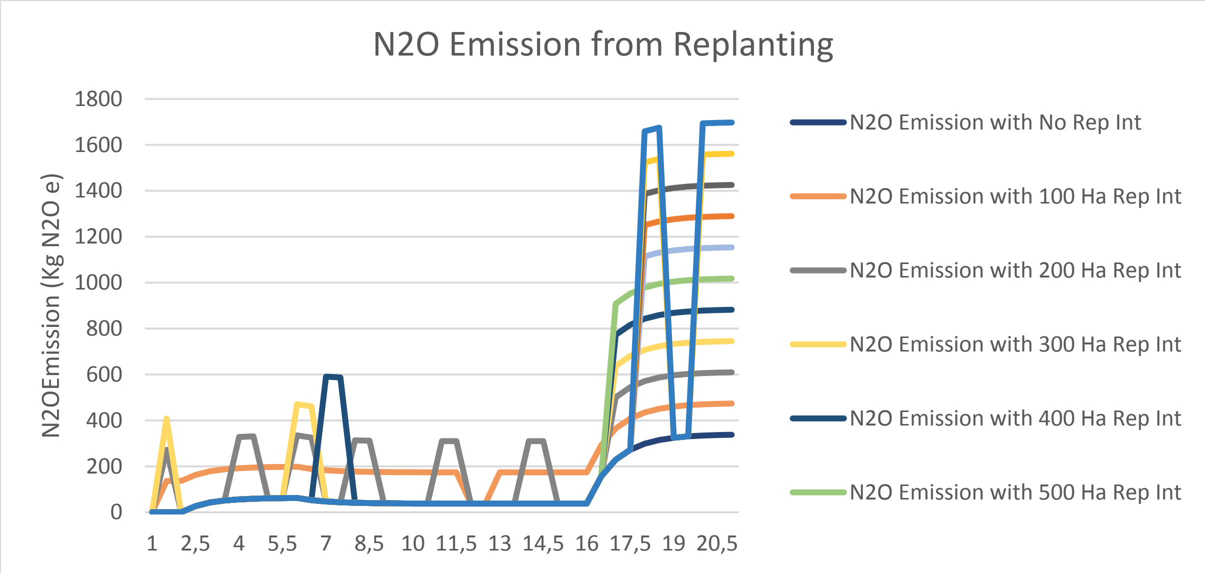

Replanting Impact on CO2 Sequestration
CO2 Sequestration (Ton)
70000
60000
50000
40000
30000
20000
10000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
CO2 Sequestration with no Rep Int
CO2 Sequestration with 100 Ha Rep Int
CO2 Sequestration with 200 Ha Rep Int
CO2 Sequestration with 300 Ha Rep Int
CO2 Sequestration with 400 Ha Rep Int
CO2 Sequestration with 500 Ha Rep Int


Replanting Impact on Carbon Stocks (Ton) for Simalungun District
Carbon Stock (Ton)
1200000
1000000
800000
600000
400000
200000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
Carbon Stocks with No Rep Int
Carbon Stocks with 100 Ha Rep Int
Carbon Stocks with 200 Ha Rep Int
Carbon Stocks with 300 Ha Rep Int
Carbon Stocks with 400 Ha Rep Int
Carbon Stocks with 500 Ha Rep Int

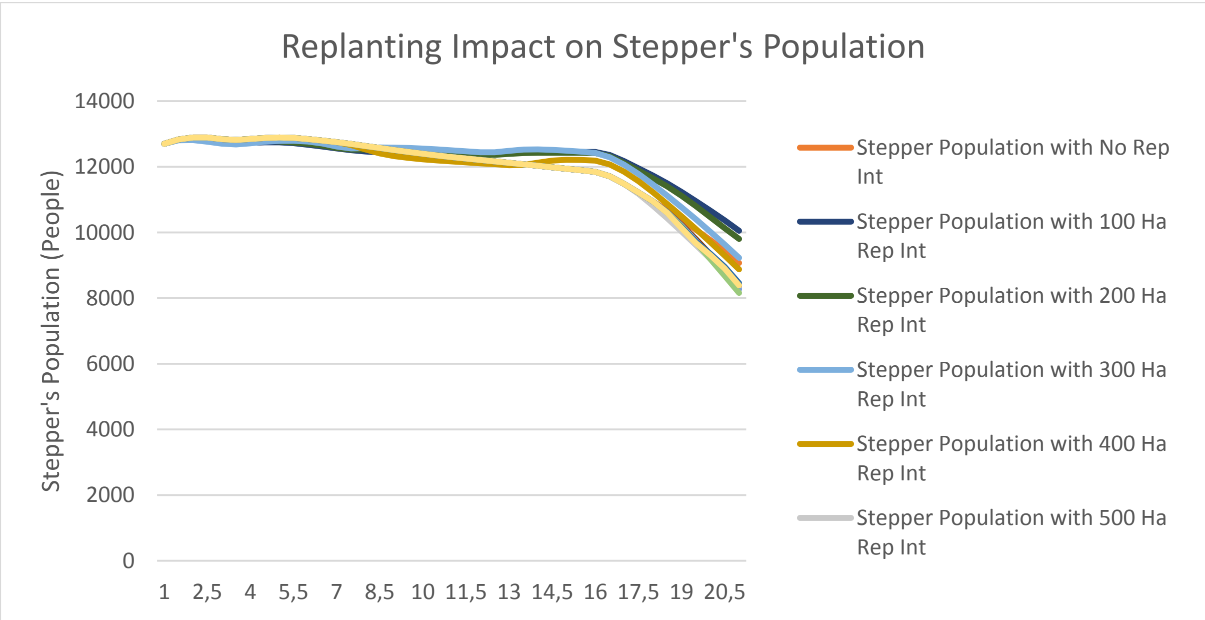

Replanting Impact on Emission from Fertilizer Use
Emission from Fertilizer (Kg CO2 e)
1400000
1200000
1000000
800000
600000
400000
200000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
Emission from Fertilizer with No Rep Int
Emission from Fertilizer with 100 Ha Rep Int
Emission from Fertilizer with 200 Ha Rep Int
Emission from Fertilizer with 300 Ha Rep Int
Emission from Fertilizer with 400 Ha Rep Int
Emission from Fertilizer with 500 Ha Rep Int


Replanting Impact on Emission from Herbicide Use
Emission from Herbicide(Kg CO2 e)
600000
500000
400000
300000
200000
100000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
Emission from Herbicide with No Rep Int
Emission from Herbicide with 100 Ha Rep Int
Emission from Herbicide with 200 Ha Rep Int
Emission from Herbicide with 300 Ha Rep Int
Emission from Herbicide with 400 Ha Rep Int
Emission from Herbicide with 500 Ha Rep Int

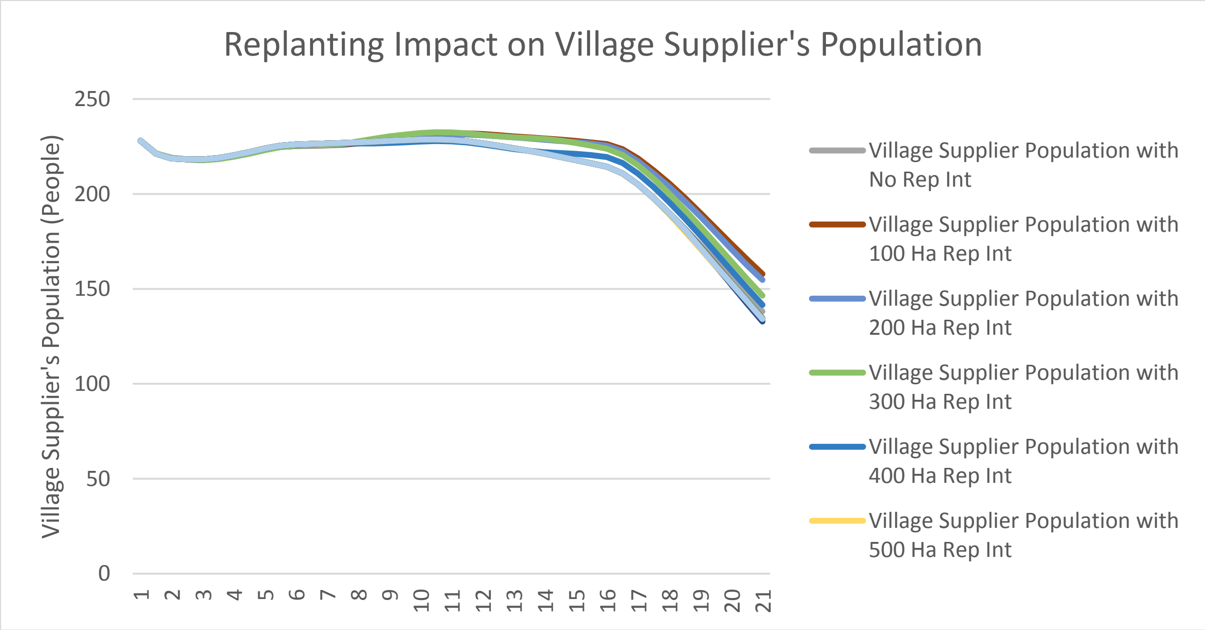

CH4 Emission from Replanting
CH4 Emission (Kg CH4 e)
70000
60000
50000
40000
30000
20000
10000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
CH4 Emission with No Rep Int
CH4 Emission with 100 Ha Rep Int
CH4 Emission with 200 Ha Rep Int
CH4 Emission with 300 Ha Rep Int
CH4 Emission with 400 Ha Rep Int
CH4 Emission with 500 Ha Rep Int

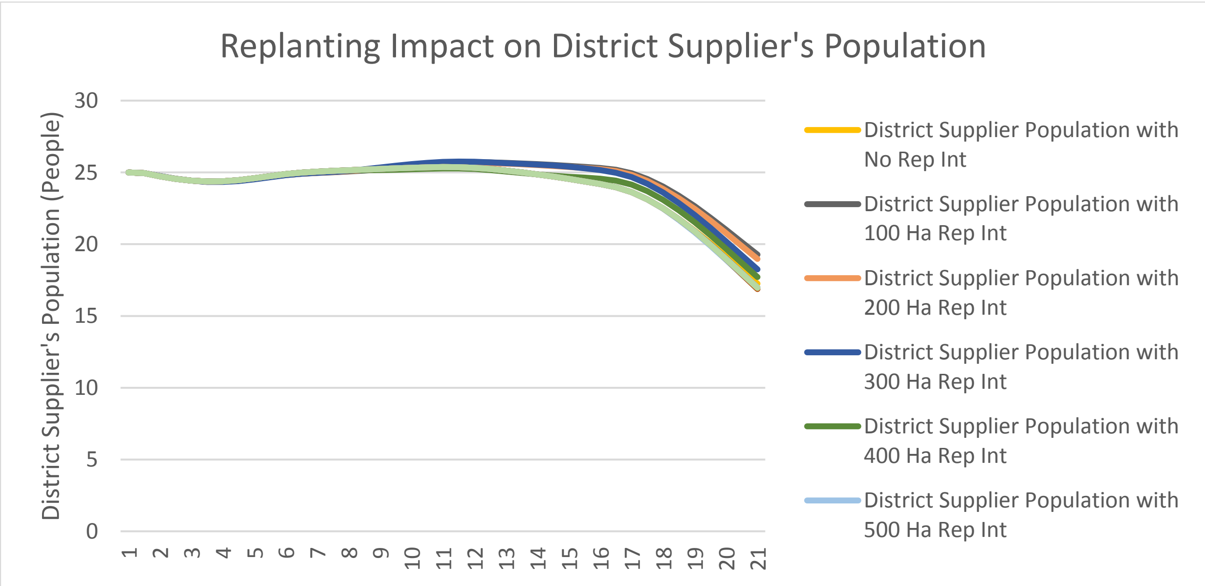


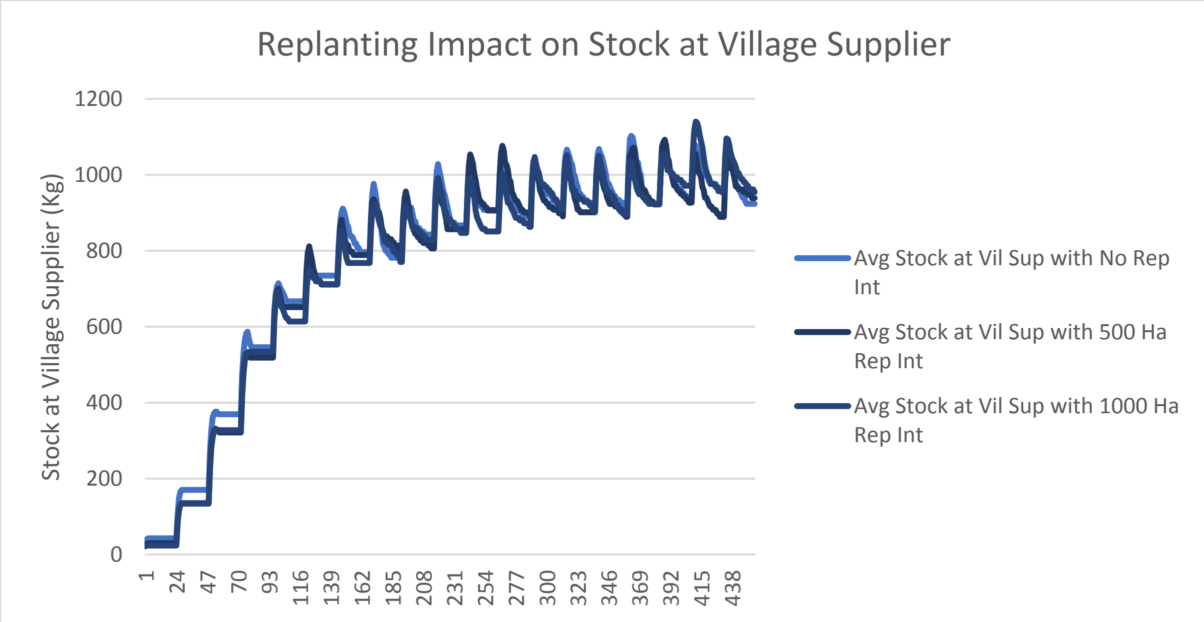
N2O Emission from Replanting
N2OEmission (Kg N2O e)
1800
1600
1400
1200
1000
800
600
400
200
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
N2O Emission with No Rep Int
N2O Emission with 100 Ha Rep Int
N2O Emission with 200 Ha Rep Int
N2O Emission with 300 Ha Rep Int
N2O Emission with 400 Ha Rep Int
N2O Emission with 500 Ha Rep Int

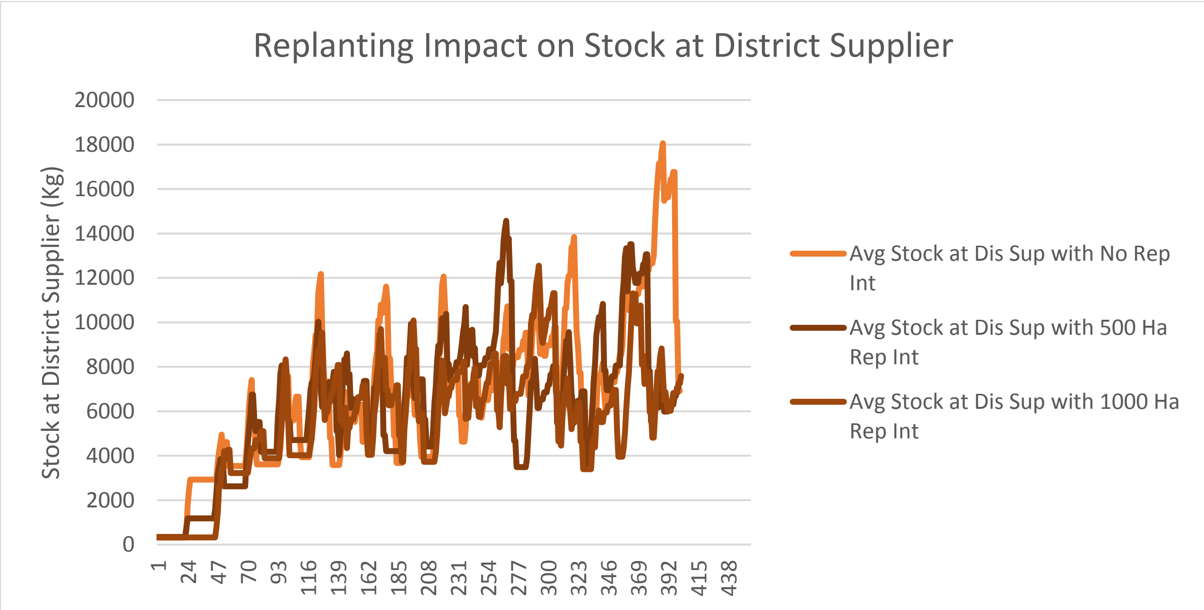


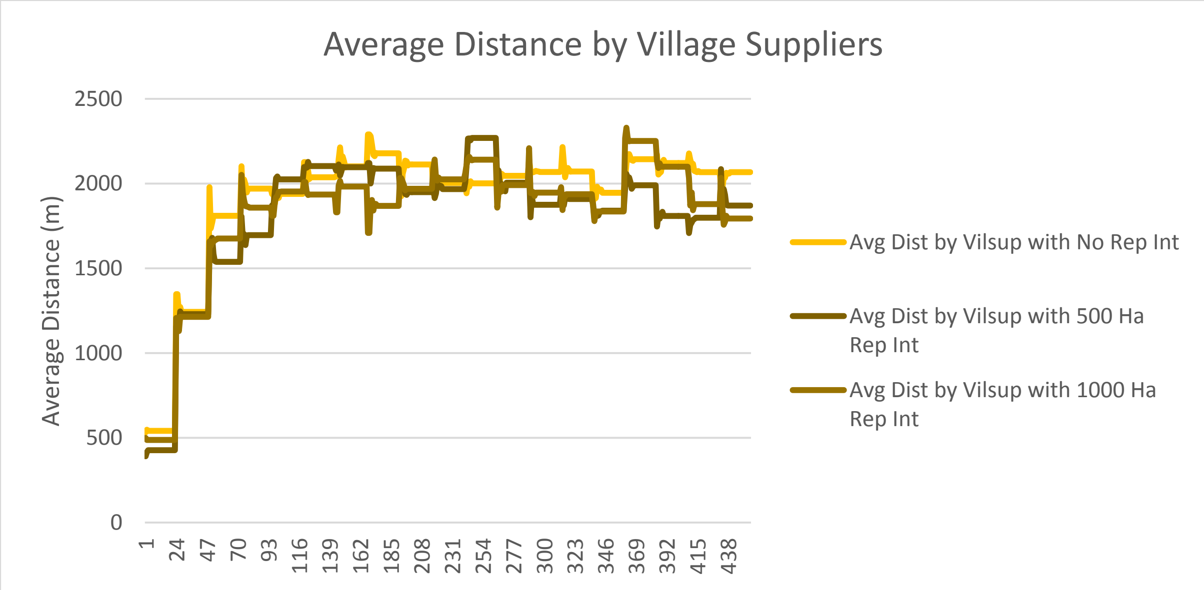
Replanting Impact on Stepper's Population
Stepper's Population (People)
14000
12000
10000
8000
6000
4000
2000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
Stepper Population with No Rep Int
Stepper Population with 100 Ha Rep Int
Stepper Population with 200 Ha Rep Int
Stepper Population with 300 Ha Rep Int
Stepper Population with 400 Ha Rep Int
Stepper Population with 500 Ha Rep Int

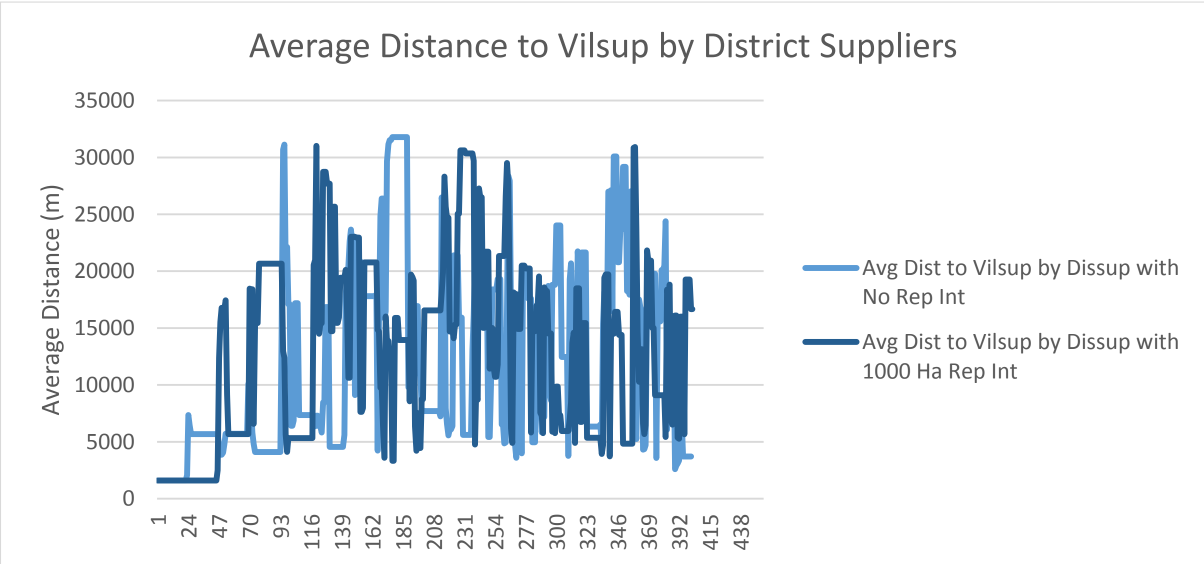

Replanting Impact on Village Supplier's Population
Village Supplier's Population (People)
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Village Supplier Population with No Rep Int
Village Supplier Population with 100 Ha Rep Int
Village Supplier Population with 200 Ha Rep Int
Village Supplier Population with 300 Ha Rep Int
Village Supplier Population with 400 Ha Rep Int
Village Supplier Population with 500 Ha Rep Int

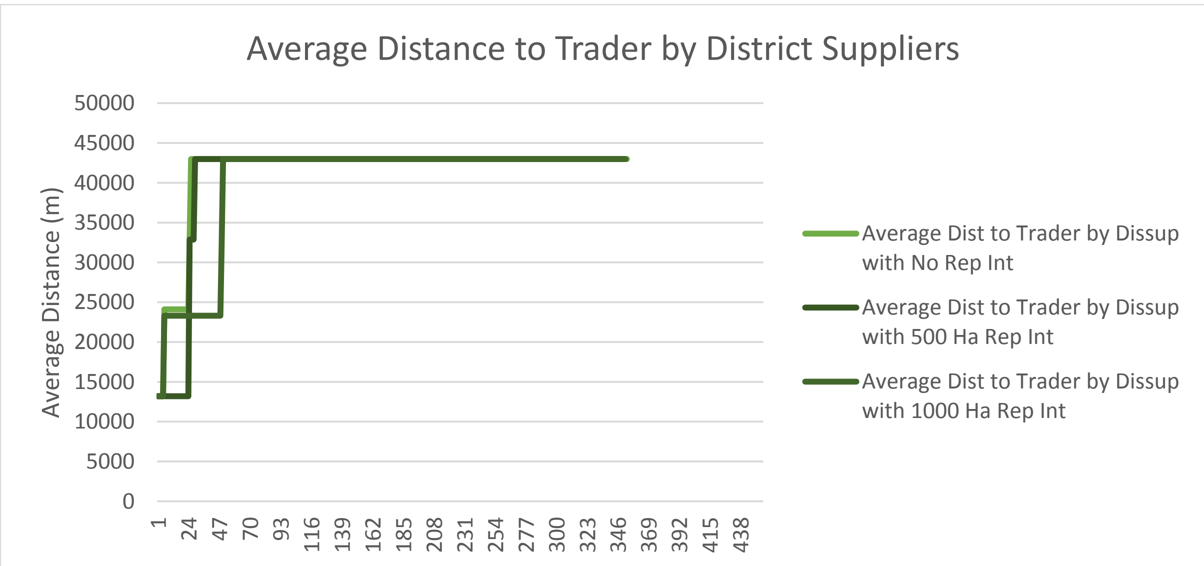

Replanting Impact on District Supplier's Population
District Supplier's Population (People)
30
25
20
15
10
5
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
District Supplier Population with No Rep Int
District Supplier Population with 100 Ha Rep Int
District Supplier Population with 200 Ha Rep Int
District Supplier Population with 300 Ha Rep Int
District Supplier Population with 400 Ha Rep Int
District Supplier Population with 500 Ha Rep Int


Replanting Impact on Stock at Village Supplier
Stock at Village Supplier (Kg)
1200
1000
800
600
400
200
0
1
24
47
70
93
116
139
162
185
208
231
254
277
300
323
346
369
392
415
438
Avg Stock at Vil Sup with No Rep Int
Avg Stock at Vil Sup with 500 Ha Rep Int
Avg Stock at Vil Sup with 1000 Ha Rep Int

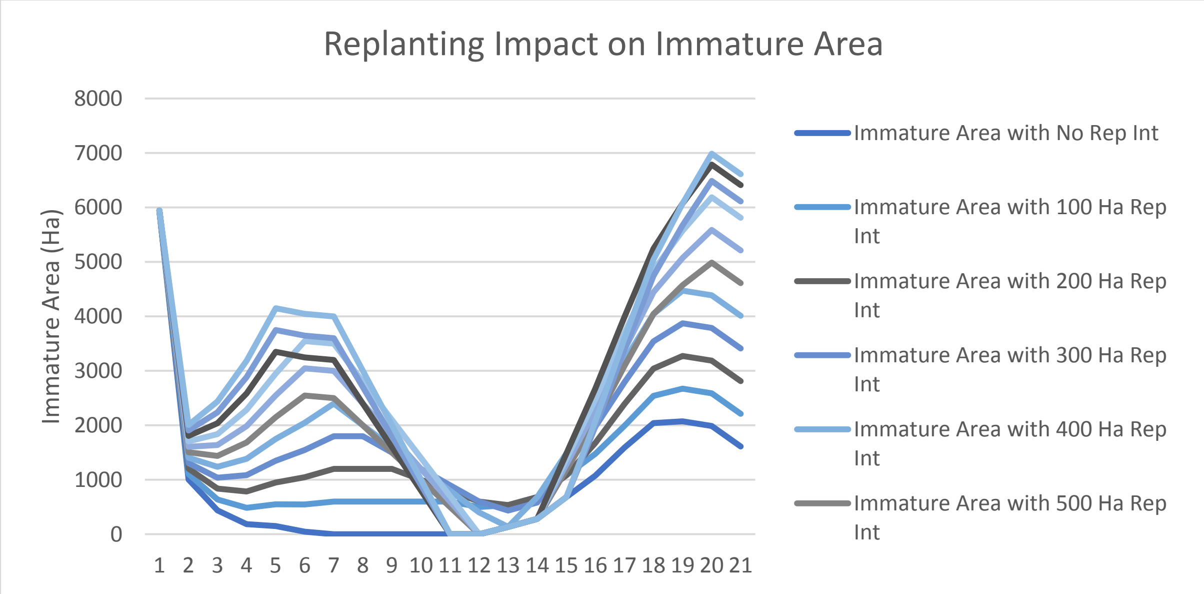

Replanting Impact on Stock at District Supplier
Stock at District Supplier (Kg)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
1
24
47
70
93
116
139
162
185
208
231
254
277
300
323
346
369
392
415
438
Avg Stock at Dis Sup with No Rep Int
Avg Stock at Dis Sup with 500 Ha Rep Int
Avg Stock at Dis Sup with 1000 Ha Rep Int

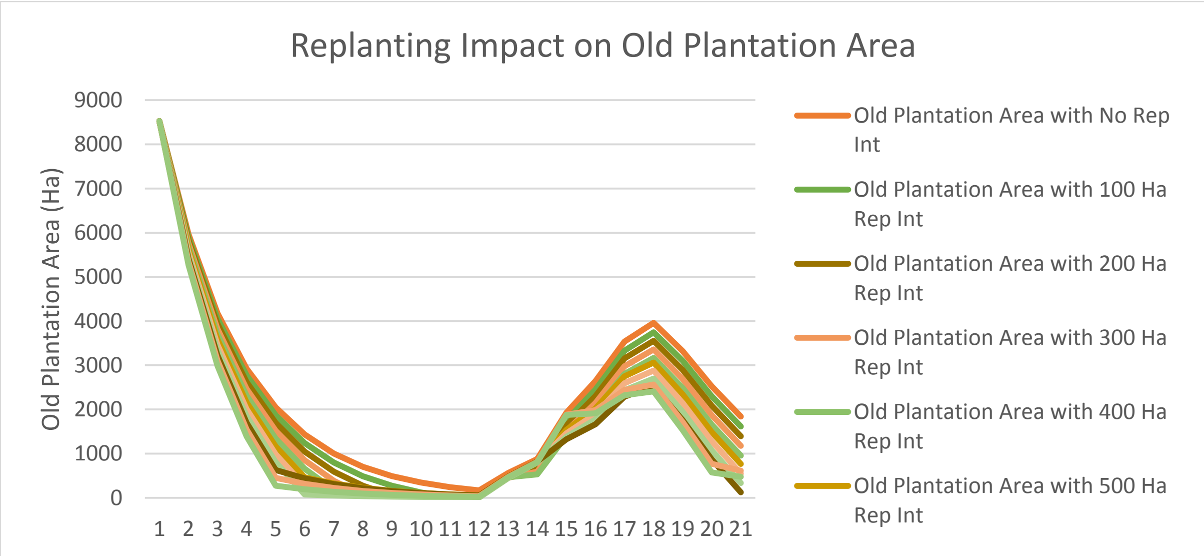

Average Distance by Village Suppliers
Average Distance (m)
2500
2000
1500
1000
500
0
1
24
47
70
93
116
139
162
185
208
231
254
277
300
323
346
369
392
415
438
Avg Dist by Vilsup with No Rep Int
Avg Dist by Vilsup with 500 Ha Rep Int
Avg Dist by Vilsup with 1000 Ha Rep Int

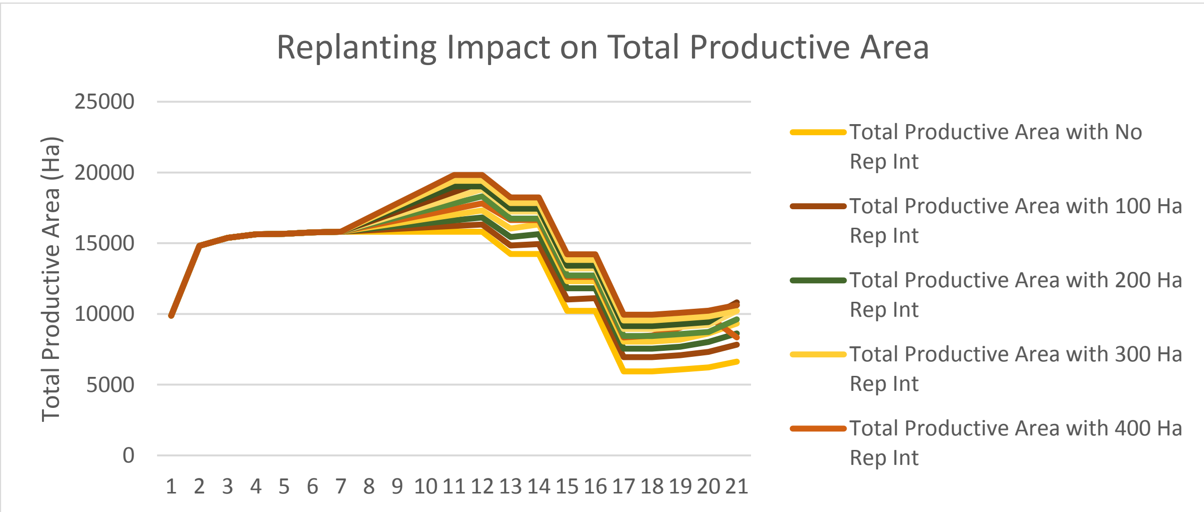

Average Distance to Vilsup by District Suppliers
Average Distance (m)
35000
30000
25000
20000
15000
10000
5000
0
1
24
47
70
93
116
139
162
185
208
231
254
277
300
323
346
369
392
415
438
Avg Dist to Vilsup by Dissup with No Rep Int
Avg Dist to Vilsup by Dissup with 1000 Ha Rep Int

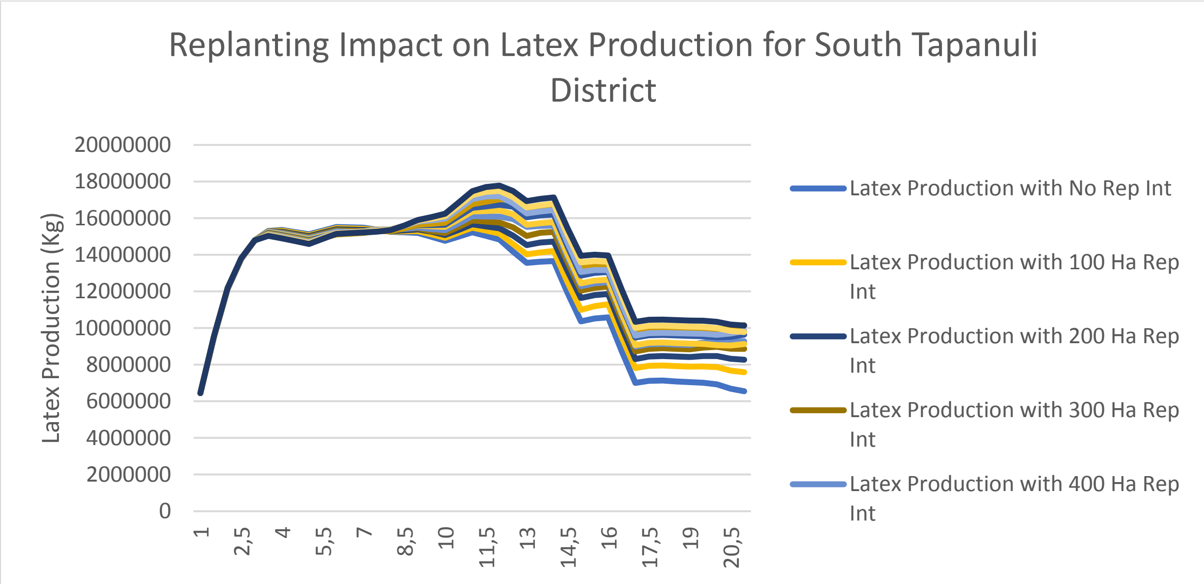

Average Distance to Trader by District Suppliers
Average Distance (m)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
1
24
47
70
93
116
139
162
185
208
231
254
277
300
323
346
369
392
415
438
Average Dist to Trader by Dissup with No Rep Int
Average Dist to Trader by Dissup with 500 Ha Rep Int
Average Dist to Trader by Dissup with 1000 Ha Rep Int

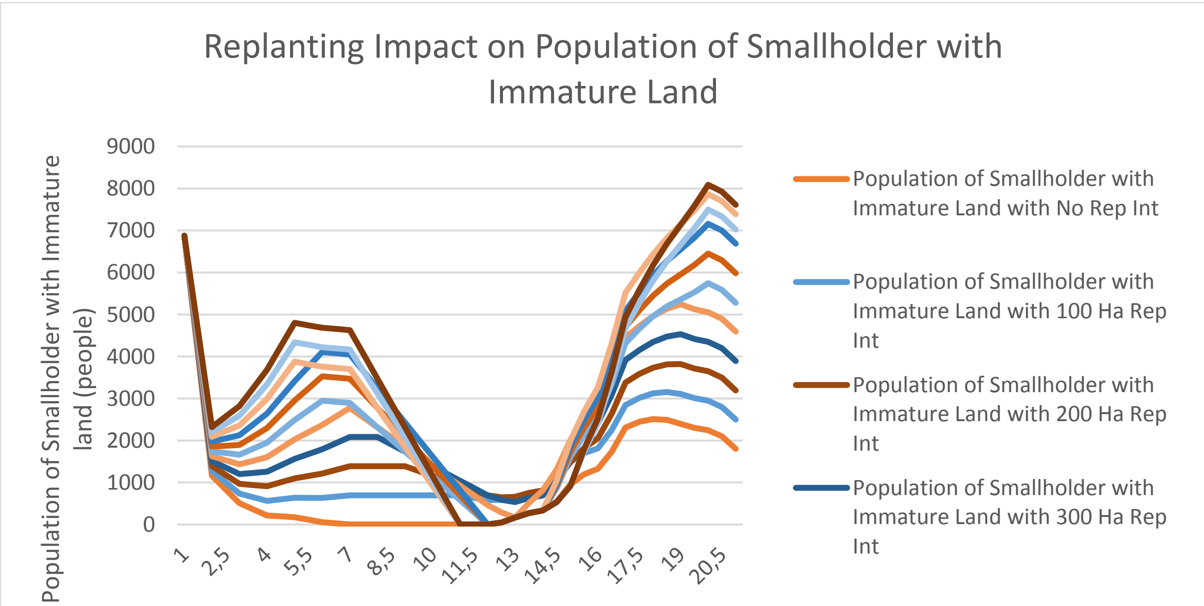
E.4 Simulation Result for South Tapanuli District

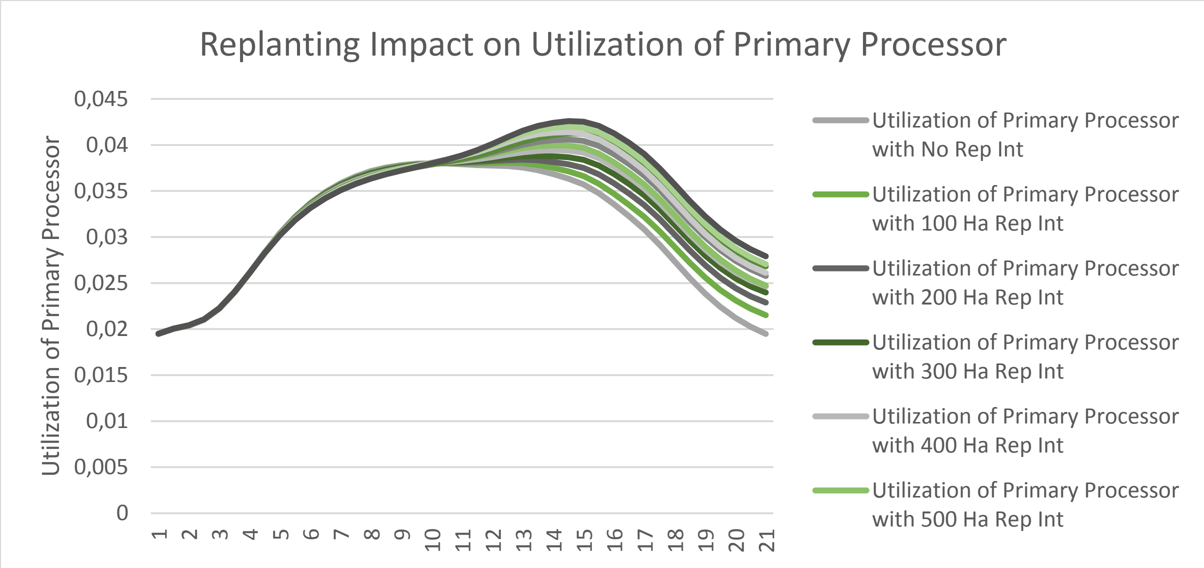




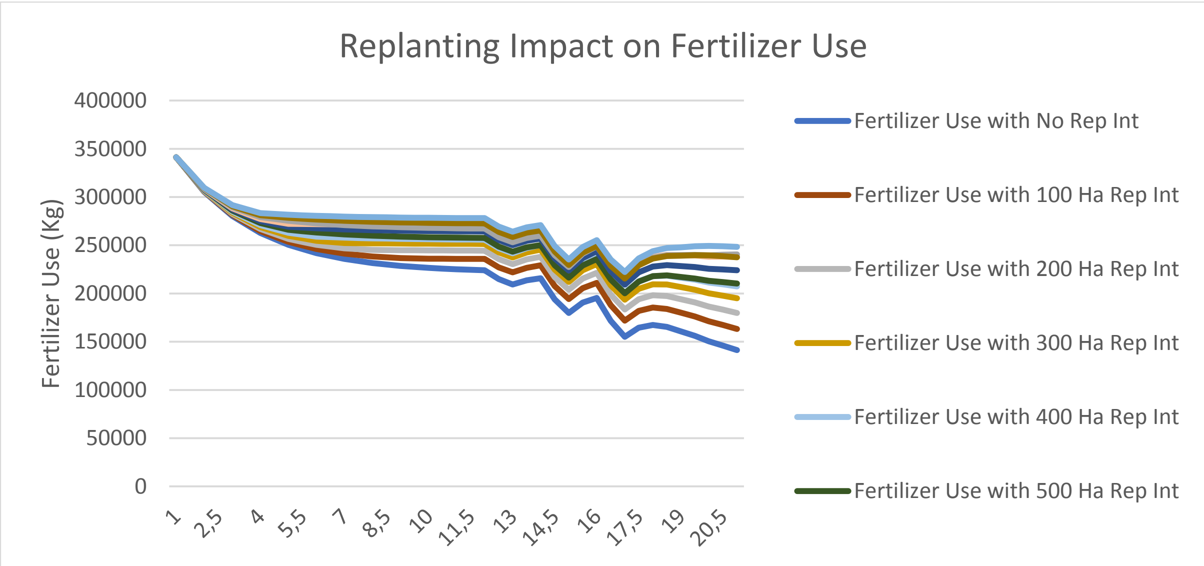



Replanting Impact on Latex Production for South Tapanuli District
Latex Production (Kg)
20000000
18000000
16000000
14000000
12000000
10000000
8000000
6000000
4000000
2000000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
Latex Production with No Rep Int
Latex Production with 100 Ha Rep Int
Latex Production with 200 Ha Rep Int
Latex Production with 300 Ha Rep Int
Latex Production with 400 Ha Rep Int

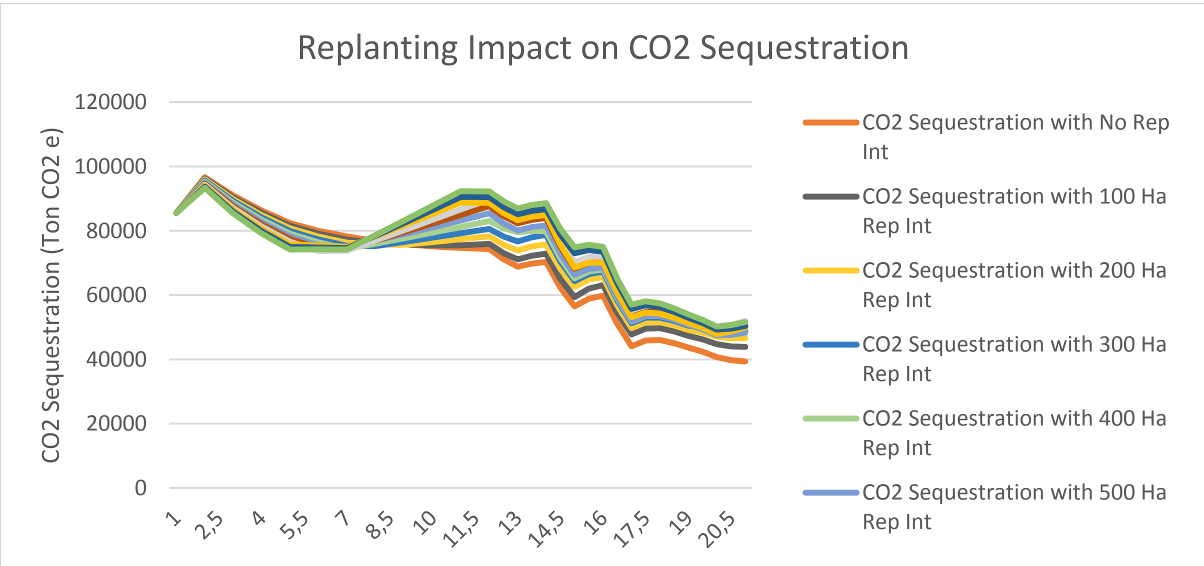

Replanting Impact on Population of Smallholder with Immature Land
Population of Smallholder with Immature land (people)
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
Population of Smallholder with Immature Land with No Rep Int
Population of Smallholder with Immature Land with 100 Ha Rep Int
Population of Smallholder with Immature Land with 200 Ha Rep Int
Population of Smallholder with Immature Land with 300 Ha Rep Int



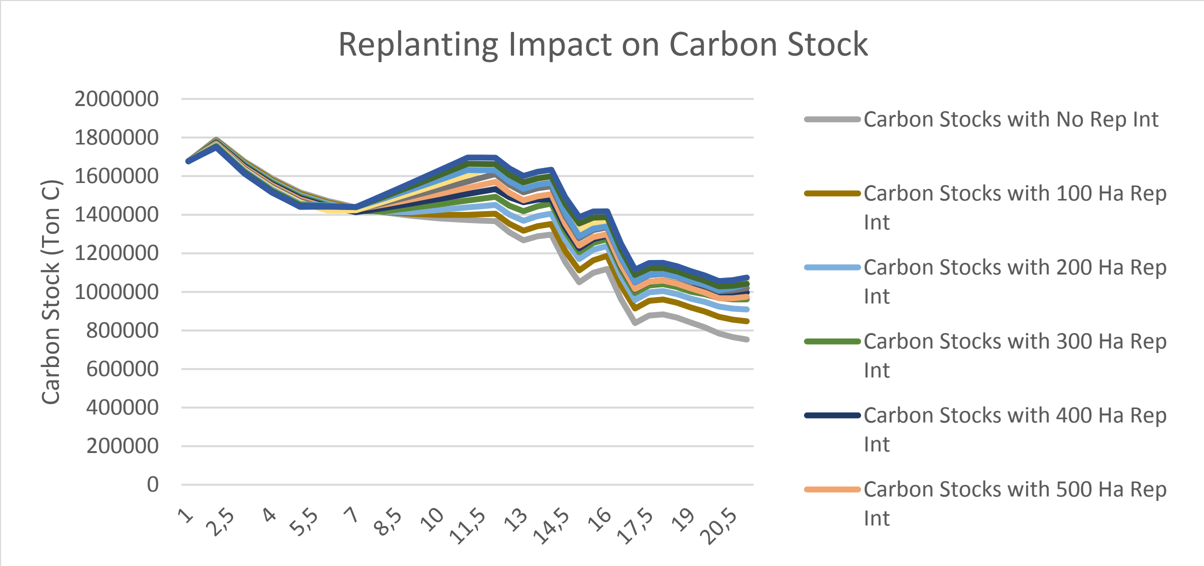
Replanting Impact on Utilization of Primary Processor
Utilization of Primary Processor
0,045
0,04
0,035
0,03
0,025
0,02
0,015
0,01
0,005
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
Utilization of Primary Processor with No Rep Int
Utilization of Primary Processor with 100 Ha Rep Int
Utilization of Primary Processor with 200 Ha Rep Int
Utilization of Primary Processor with 300 Ha Rep Int
Utilization of Primary Processor with 400 Ha Rep Int
Utilization of Primary Processor with 500 Ha Rep Int

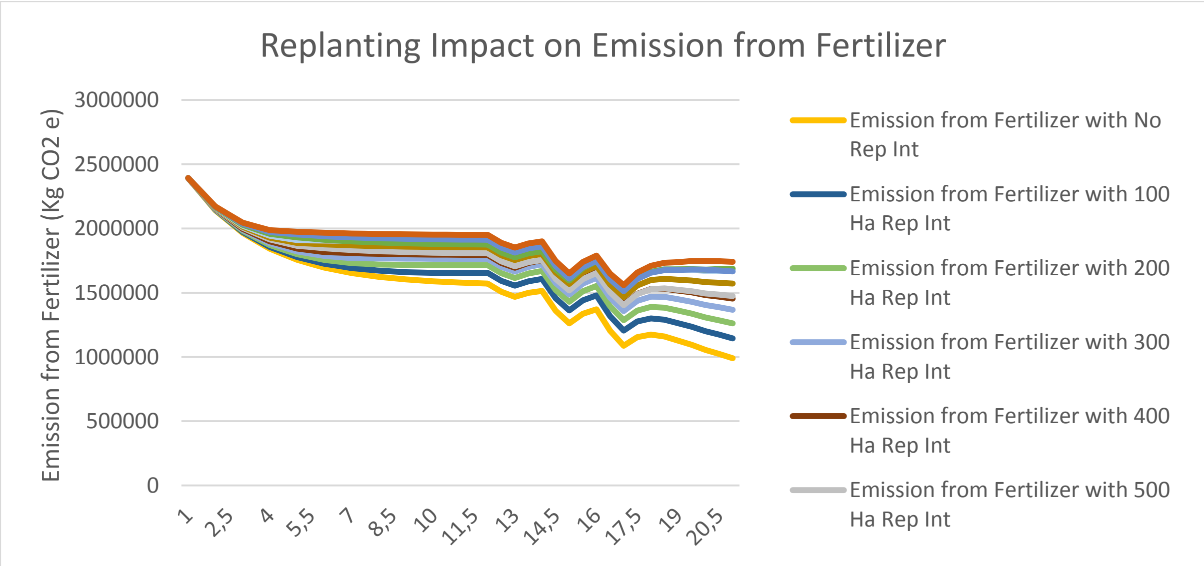


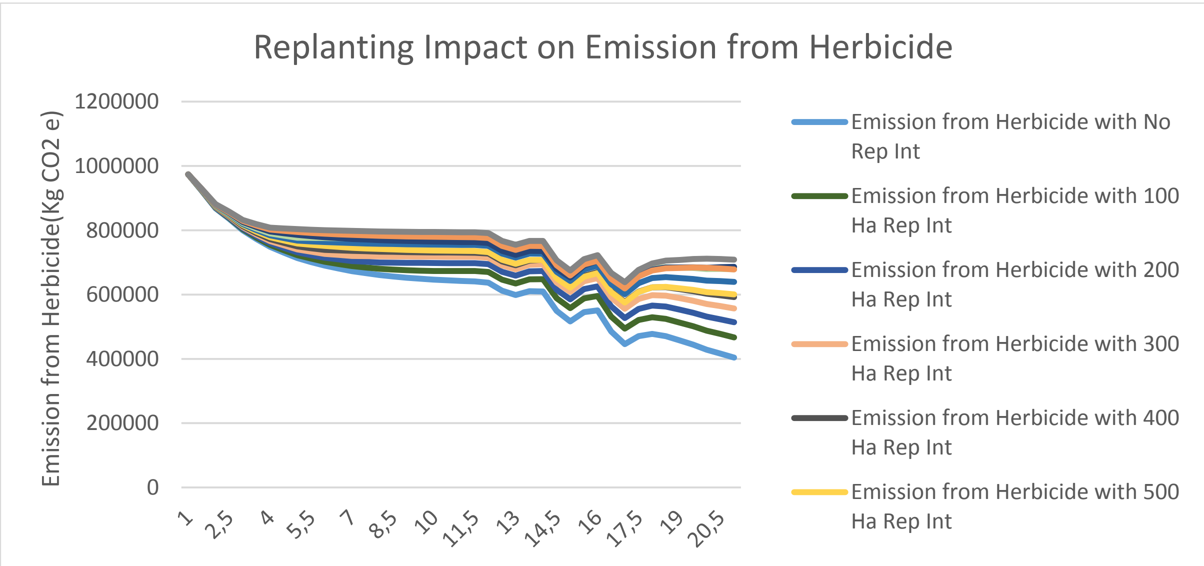
Replanting Impact on Fertilizer Use
Fertilizer Use (Kg)
400000
350000
300000
250000
200000
150000
100000
50000
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
Fertilizer Use with No Rep Int
Fertilizer Use with 100 Ha Rep Int
Fertilizer Use with 200 Ha Rep Int
Fertilizer Use with 300 Ha Rep Int
Fertilizer Use with 400 Ha Rep Int
Fertilizer Use with 500 Ha Rep Int

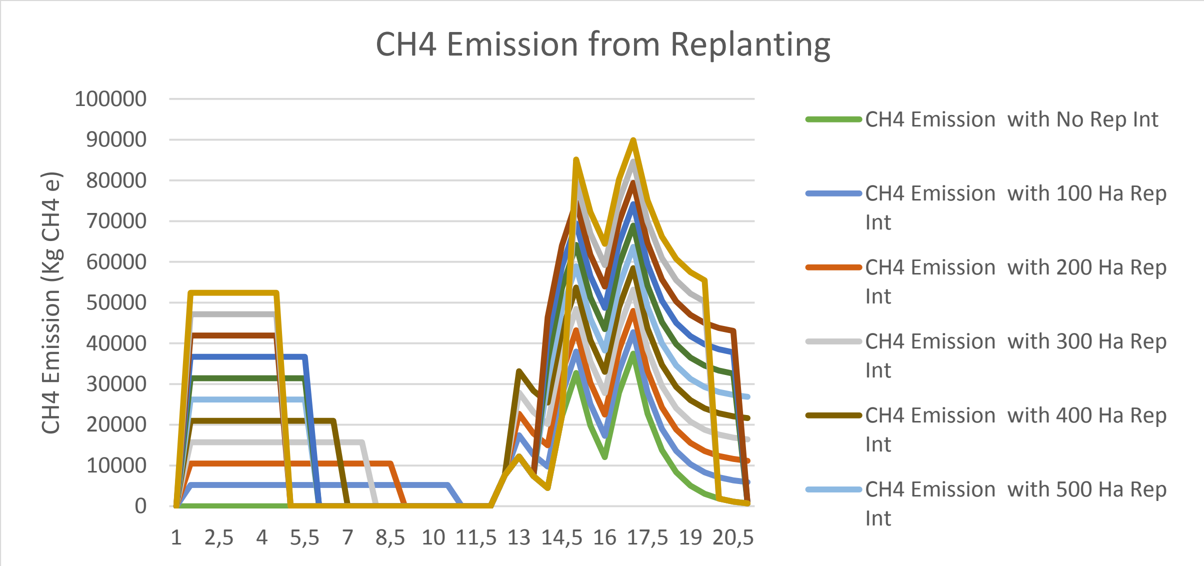


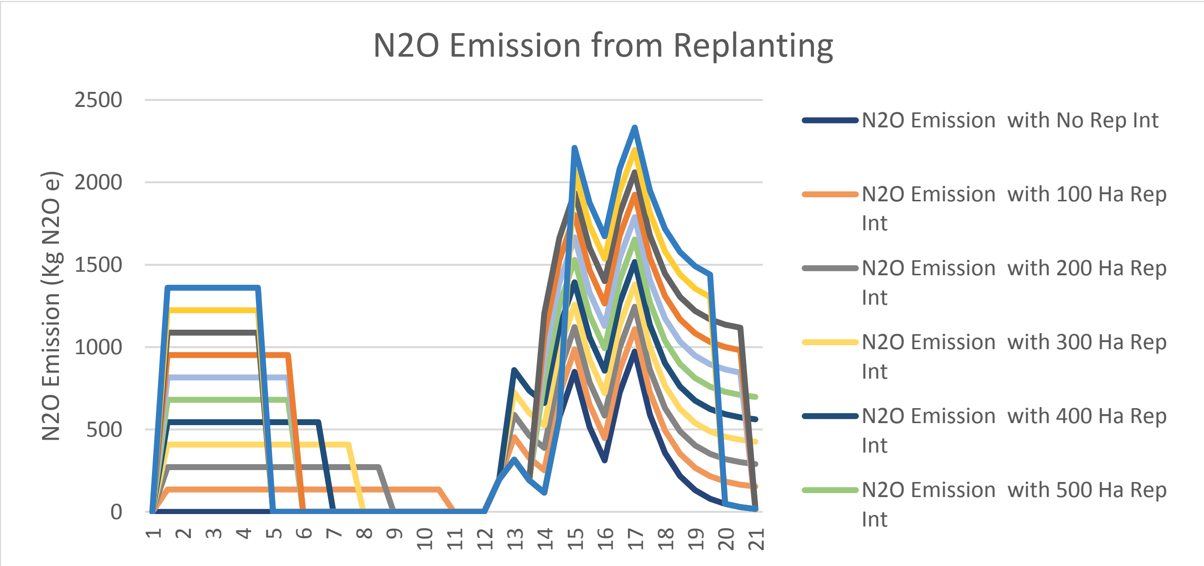
Replanting Impact on CO2 Sequestration
CO2 Sequestration (Ton CO2 e)
120000
100000
80000
60000
40000
20000
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
CO2 Sequestration with No Rep Int
CO2 Sequestration with 100 Ha Rep Int
CO2 Sequestration with 200 Ha Rep Int
CO2 Sequestration with 300 Ha Rep Int
CO2 Sequestration with 400 Ha Rep Int
CO2 Sequestration with 500 Ha Rep Int

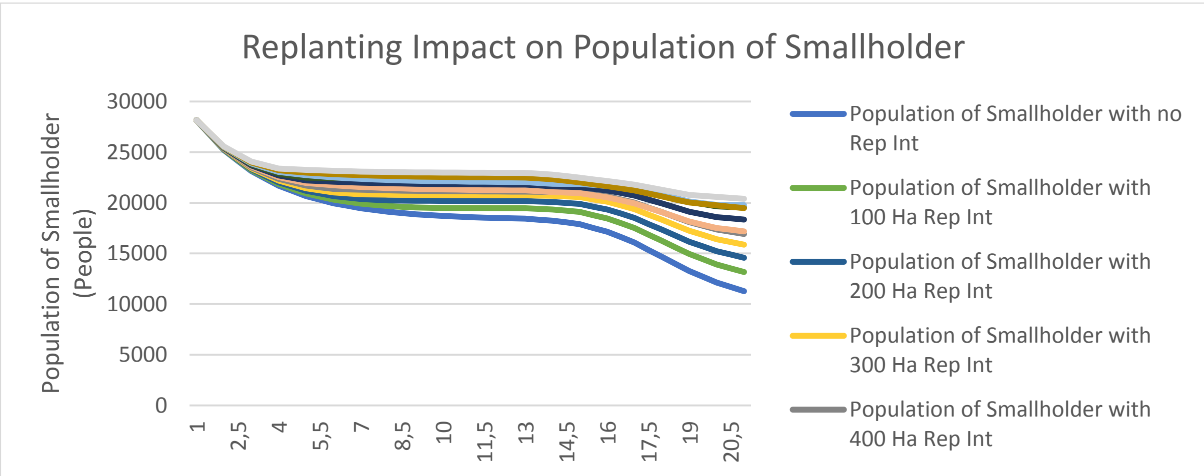

Replanting Impact on Carbon Stock
Carbon Stock (Ton C)
2000000
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
Carbon Stocks with No Rep Int
Carbon Stocks with 100 Ha Rep Int
Carbon Stocks with 200 Ha Rep Int
Carbon Stocks with 300 Ha Rep Int
Carbon Stocks with 400 Ha Rep Int
Carbon Stocks with 500 Ha Rep Int

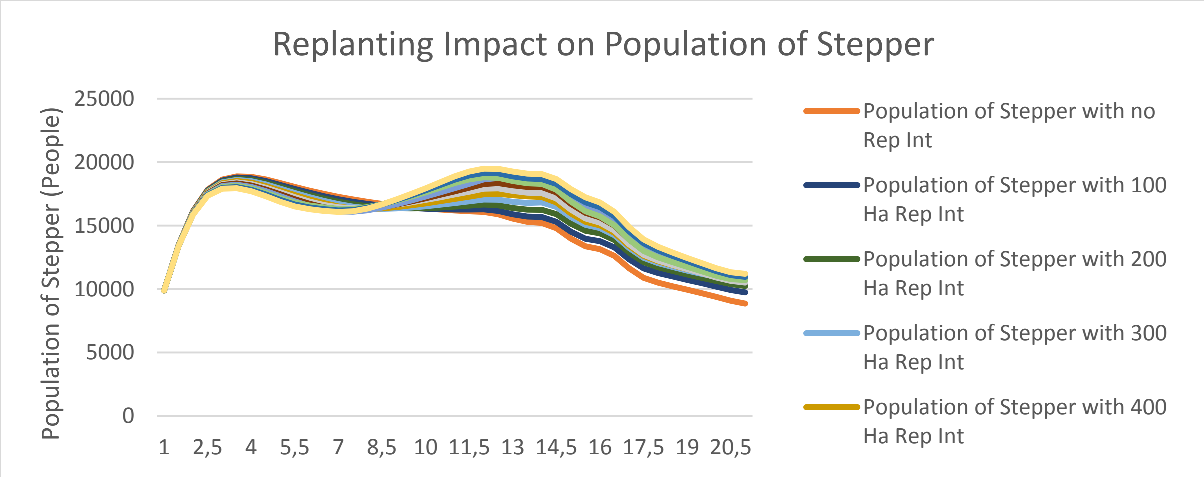

Replanting Impact on Emission from Fertilizer
Emission from Fertilizer (Kg CO2 e)
3000000
2500000
2000000
1500000
1000000
500000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
Emission from Fertilizer with No Rep Int
Emission from Fertilizer with 100 Ha Rep Int
Emission from Fertilizer with 200 Ha Rep Int
Emission from Fertilizer with 300 Ha Rep Int
Emission from Fertilizer with 400 Ha Rep Int
Emission from Fertilizer with 500 Ha Rep Int

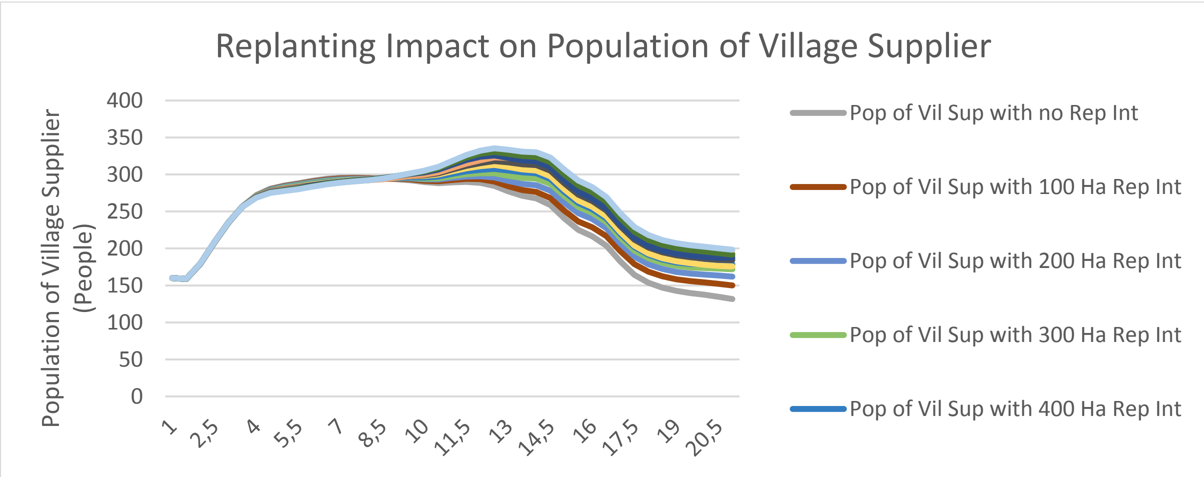

Replanting Impact on Emission from Herbicide
Emission from Herbicide(Kg CO2 e)
1200000
1000000
800000
600000
400000
200000
0
1
2,5
4
5,5
7
8,5
10
11,5
13
14,5
16
17,5
19
20,5
Emission from Herbicide with No Rep Int
Emission from Herbicide with 100 Ha Rep Int
Emission from Herbicide with 200 Ha Rep Int
Emission from Herbicide with 300 Ha Rep Int
Emission from Herbicide with 400 Ha Rep Int
Emission from Herbicide with 500 Ha Rep Int

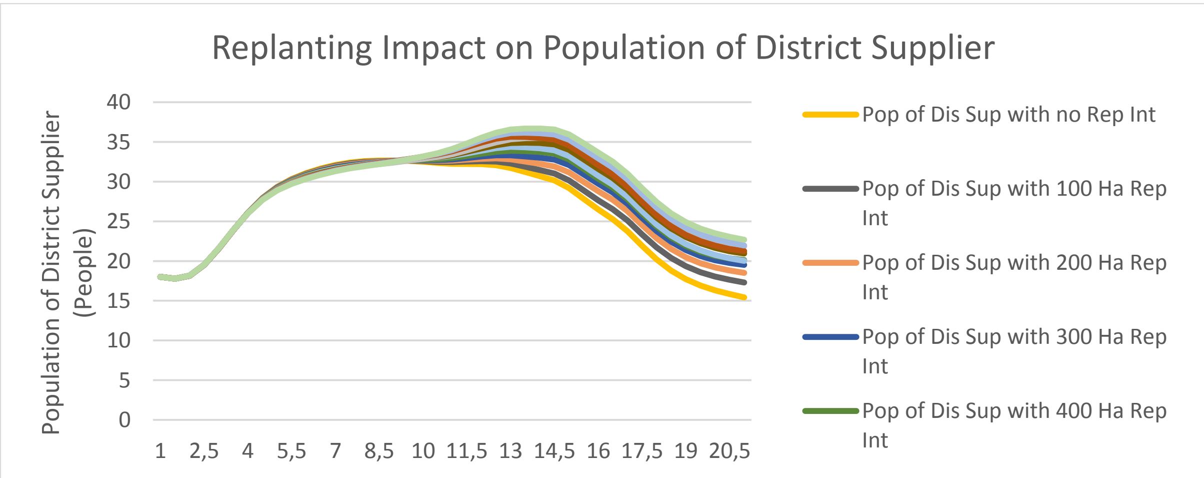

CH4 Emission from Replanting
CH4 Emission (Kg CH4 e)
100000
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
CH4 Emission with No Rep Int
CH4 Emission with 100 Ha Rep Int
CH4 Emission with 200 Ha Rep Int
CH4 Emission with 300 Ha Rep Int
CH4 Emission with 400 Ha Rep Int
CH4 Emission with 500 Ha Rep Int

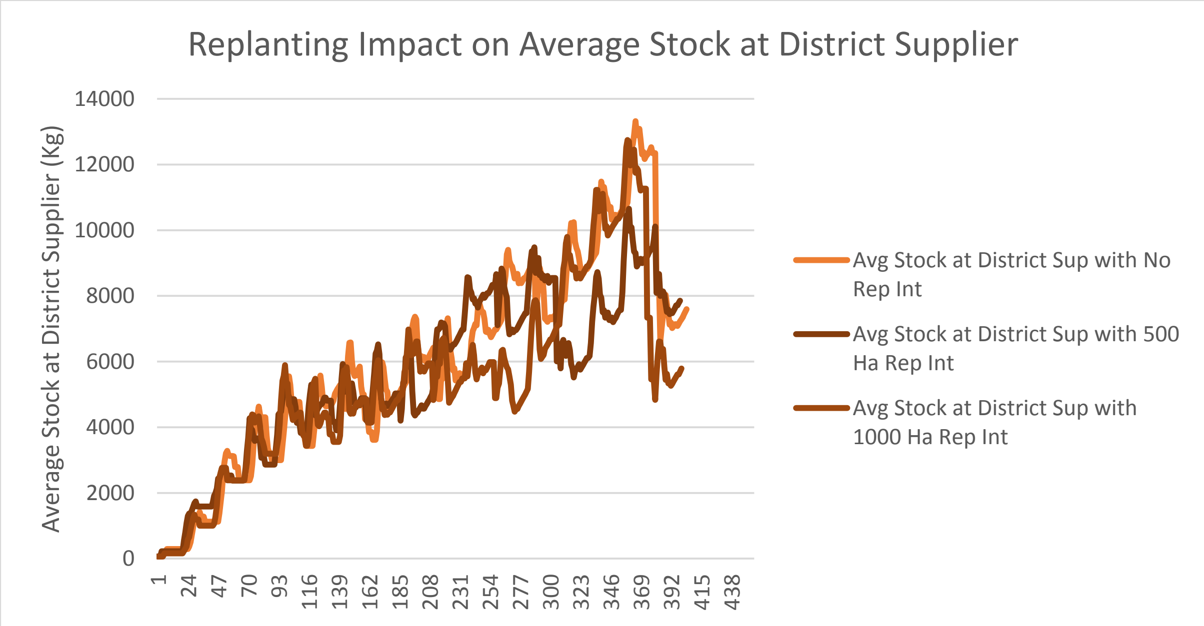

N2O Emission from Replanting
N2O Emission (Kg N2O e)
2500
2000
1500
1000
500
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21
N2O Emission with No Rep Int
N2O Emission with 100 Ha Rep Int
N2O Emission with 200 Ha Rep Int
N2O Emission with 300 Ha Rep Int
N2O Emission with 400 Ha Rep Int
N2O Emission with 500 Ha Rep Int


Replanting Impact on Population of Smallholder
Population of Smallholder (People)
30000
25000
20000
15000
10000
5000
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
Population of Smallholder with no Rep Int
Population of Smallholder with 100 Ha Rep Int
Population of Smallholder with 200 Ha Rep Int
Population of Smallholder with 300 Ha Rep Int
Population of Smallholder with 400 Ha Rep Int

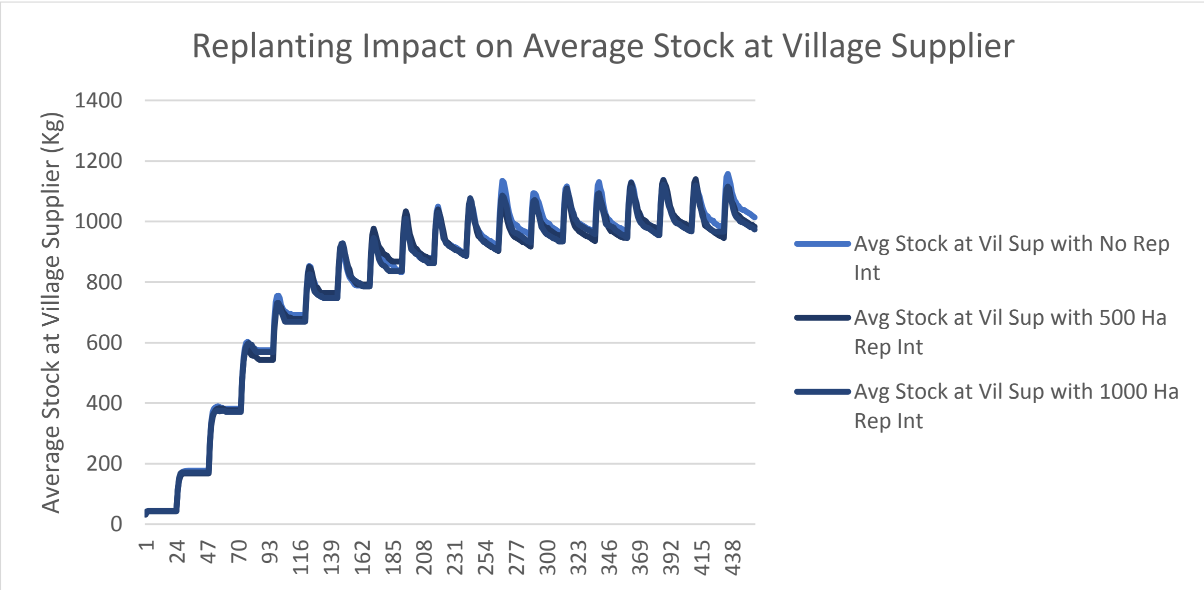

Replanting Impact on Population of Stepper
Population of Stepper (People)
25000
20000
15000
10000
5000
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
Population of Stepper with no Rep Int
Population of Stepper with 100 Ha Rep Int
Population of Stepper with 200 Ha Rep Int
Population of Stepper with 300 Ha Rep Int
Population of Stepper with 400 Ha Rep Int


Replanting Impact on Population of Village Supplier
Population of Village Supplier (People)
400
350
300
250
200
150
100
50
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
Pop of Vil Sup with no Rep Int
Pop of Vil Sup with 100 Ha Rep Int
Pop of Vil Sup with 200 Ha Rep Int
Pop of Vil Sup with 300 Ha Rep Int
Pop of Vil Sup with 400 Ha Rep Int

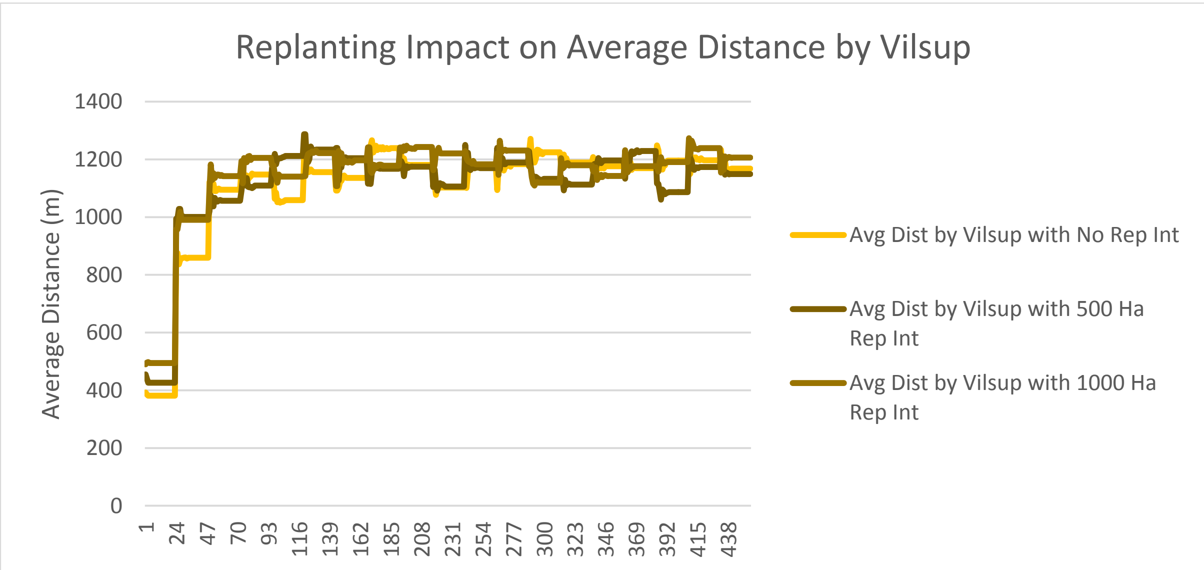

Replanting Impact on Population of District Supplier
Population of District Supplier (People)
40
35
30
25
20
15
10
5
0
1 2,5 4 5,5 7 8,5 10 11,5 13 14,5 16 17,5 19 20,5
Pop of Dis Sup with no Rep Int
Pop of Dis Sup with 100 Ha Rep Int
Pop of Dis Sup with 200 Ha Rep Int
Pop of Dis Sup with 300 Ha Rep Int
Pop of Dis Sup with 400 Ha Rep Int



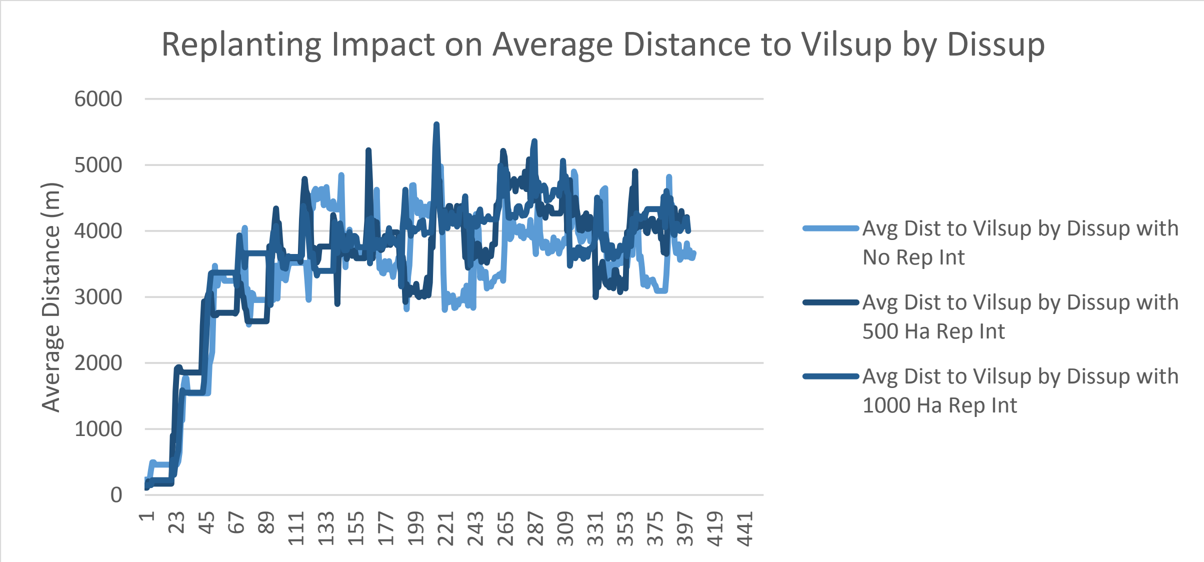
Replanting Impact on Average Stock at District Supplier
Average Stock at District Supplier (Kg)
14000
12000
10000
8000
6000
4000
2000
0
1
24
47
70
93
116
139
162
185
208
231
254
277
300
323
346
369
392
415
438
Avg Stock at District Sup with No Rep Int
Avg Stock at District Sup with 500 Ha Rep Int
Avg Stock at District Sup with 1000 Ha Rep Int

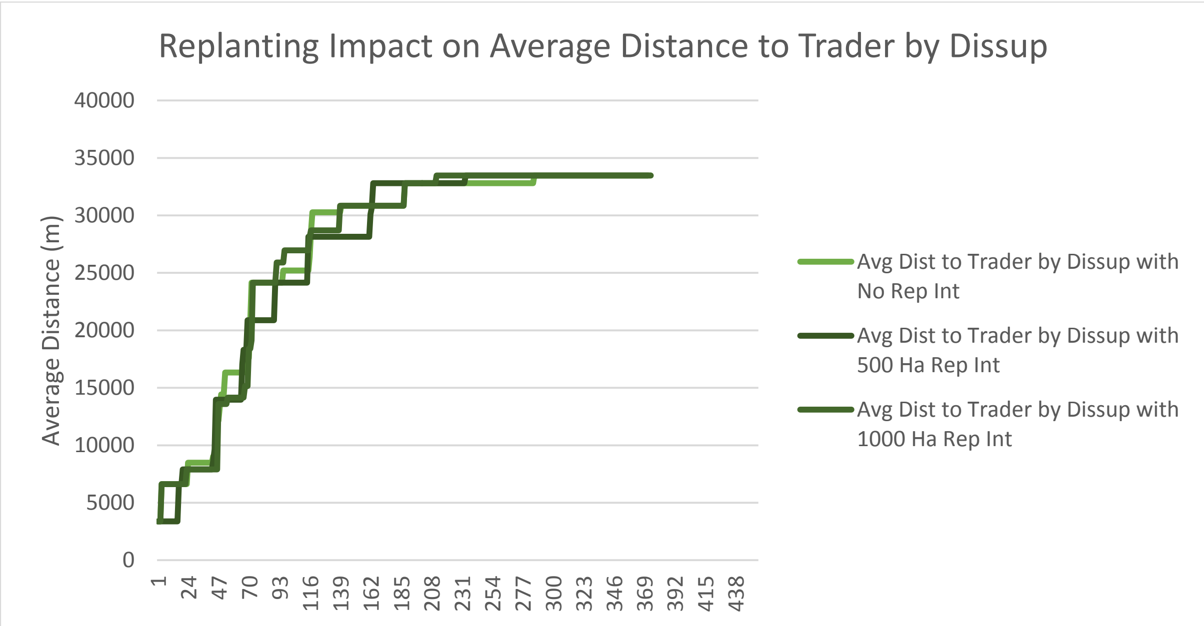


Replanting Impact on Average Stock at Village Supplier
Average Stock at Village Supplier (Kg)
1400
1200
1000
800
600
400
200
0
1
24
47
70
93
116
139
162
185
208
231
254
277
300
323
346
369
392
415
438
Avg Stock at Vil Sup with No Rep Int
Avg Stock at Vil Sup with 500 Ha Rep Int
Avg Stock at Vil Sup with 1000 Ha Rep Int



Replanting Impact on Average Distance by Vilsup
Average Distance (m)
1400
1200
1000
800
600
400
200
0
1
24
47
70
93
116
139
162
185
208
231
254
277
300
323
346
369
392
415
438
Avg Dist by Vilsup with No Rep Int
Avg Dist by Vilsup with 500 Ha Rep Int
Avg Dist by Vilsup with 1000 Ha Rep Int


Replanting Impact on Average Distance to Vilsup by Dissup
Average Distance (m)
6000
5000
4000
3000
2000
1000
0
1
23
45
67
89
111
133
155
177
199
221
243
265
287
309
331
353
375
397
419
441
Avg Dist to Vilsup by Dissup with No Rep Int
Avg Dist to Vilsup by Dissup with 500 Ha Rep Int
Avg Dist to Vilsup by Dissup with 1000 Ha Rep Int


Replanting Impact on Average Distance to Trader by Dissup
Average Distance (m)
40000
35000
30000
25000
20000
15000
10000
5000
0
1
24
47
70
93
116
139
162
185
208
231
254
277
300
323
346
369
392
415
438
Avg Dist to Trader by Dissup with No Rep Int
Avg Dist to Trader by Dissup with 500 Ha Rep Int
Avg Dist to Trader by Dissup with 1000 Ha Rep Int

Appendix F Composite Index and Dynamic Programming Result

F.1 Composite Index and Dynamic Programming Result for Deli Serdang District

Replanting Intervention allocation	Composite Index				
	Year 1 (2016)	Year 2 (2017)	Year 3 (2018)	Year 4 (2019)	Year 5 (2020)
0	84	78	78	79	75
100	87	85	85	86	83
200	91	85	85	86	83
300	94	89	89	90	87
400	97	92	93	93	91
500	84	78	78	79	75
600	84	78	78	79	75
700	84	78	78	79	75
800	84	78	78	79	75
900	84	78	78	79	75
1000	84	78	78	79	75

Total Allocation in Stage 1	Optimum Impact in Year 1 (F_1**)
0	84
100	87
200	91
300	94
400	97
500	84
600	84
700	84
800	84
900	84
1000	84

Total Allocation until Stage 2	F_1**	Impact of Replanting Intervention Allocation at Year 2											F_2**
		0	100	200	300	400	500	600	700	800	900	100	
0	84	162											162
100	87	165	169										169
200	91	169	172	169									172
300	94	172	176	172	173								176
400	97	175	179	176	176	176							179
500	84	162	182	179	180	179	162						182
600	84	162	169	182	183	183	165	162					183
700	84	162	169	169	186	186	169	165	162				186
800	84	162	169	169	173	189	172	169	165	162			189
900	84	162	169	169	173	176	175	172	169	165	162		176
1000	84	162	169	169	173	176	162	175	172	169	165	162	176

Total Allocation until Stage 3	F_2**	Impact of Replanting Intervention Allocation at Year 3											F_3**
		0	100	200	300	400	500	600	700	800	900	100	
0	162	240											240
100	169	247	247										247
200	172	250	254	247									254
300	176	254	257	254	251								257
400	179	257	261	257	258	255							261
500	182	260	264	261	261	262	240						264
600	183	261	267	264	265	265	247	240					267
700	186	264	268	267	268	269	250	247	240				269
800	189	267	271	268	271	272	254	250	247	240			272
900	176	254	274	271	272	275	257	254	250	247	240		275
1000	176	254	261	274	275	276	260	257	254	250	247	240	276

Total Allocation until Stage 4	**F_3****	**Impact of Replanting Intervention Allocation at Year 4**											**F_4****
		0	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**100**	
0	240	319											319
100	247	326	326										326
200	254	333	333	326									333
300	257	336	340	333	330								340
400	261	340	343	340	337	333							343
500	264	343	347	343	344	340	319						347
600	267	346	350	347	347	347	326	319					350
700	269	348	353	350	351	350	333	326	319				353
800	272	351	355	353	354	354	336	333	326	319			355
900	275	354	358	355	357	357	340	336	333	326	319		358
1000	276	355	361	358	359	360	343	340	336	333	326	319	361

Impact of Replanting Intervention Allocation at Year 5											**F_5****
0	100	200	300	400	500	600	700	800	900	1000	
436	441	438	440	441	422	418	415	408	401	394	441

Scenario	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Scenario 1	300	100	400	100	100
Scenario 2	300	100	100	100	400

F.2 Composite Index and Dynamic Programming Result for Asahan District

Replanting Intervention allocation	Composite Index				
	Year 1 (2016)	**Year 2 (2017)**	**Year 3 (2018)**	**Year 4 (2019)**	**Year 5 (2020)**
0	82	79	78	73	70
100	83	84	84	81	81
200	85	88	90	90	92
300	87	92	97	98	97
400	81	87	94	90	88
500	81	89	98	94	93
600	81	91	91	86	84
700	81	79	91	87	86
800	81	79	93	90	88
900	82	79	78	73	70
1000	82	79	78	73	70

Total Allocation in Stage 1	Optimum Impact in Year 1 (F_1**)
0	82
100	83
200	85
300	87
400	81
500	81
600	81
700	81
800	81
900	82
1000	82

Total Allocation until Stage 2	F_1**	Impact of Replanting Intervention Allocation at Year 2											F_2**
		0	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**100**	
0	82	161											161
100	83	162	166										166
200	85	164	167	170									170
300	87	166	169	171	174								174
400	81	160	171	173	175	169							175
500	81	160	165	175	177	170	171						177
600	81	160	165	169	179	172	172	173					179
700	81	160	165	169	173	174	174	174	161				174
800	81	160	165	169	173	168	176	176	162	161			176
900	82	161	165	169	173	168	170	178	164	162	161		178
1000	82	161	166	169	173	168	170	172	166	164	162	161	173

Total Allocation until Stage 3	F_2**	Impact of Replanting Intervention Allocation at Year 3											F_3**
		0	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**100**	
0	161	239											239
100	166	244	245										245
200	170	248	250	251									251
300	174	252	254	256	258								258
400	175	253	258	260	263	255							263
500	177	255	259	264	267	260	259						267
600	179	257	261	265	271	264	264	252					271
700	174	252	263	267	272	268	268	257	252				272
800	176	254	258	269	274	269	272	261	257	254			274
900	178	256	260	264	276	271	273	265	261	259	239		276
1000	173	251	262	266	271	273	275	266	265	263	244	239	275

Total Allocation until Stage 4	**F_3****	**Impact of Replanting Intervention Allocation at Year 4**											**F_4****
		0	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**100**	
0	239	312											312
100	245	318	320										320
200	251	324	326	329									329
300	258	331	332	335	337								337
400	263	336	339	341	343	329							343
500	267	340	344	348	349	335	333						349
600	271	344	348	353	356	341	339	325					356
700	272	345	352	357	361	348	345	331	326				361
800	274	347	353	361	365	353	352	337	332	329			365
900	276	349	355	362	369	357	357	344	338	335	312		369
1000	275	348	357	364	370	361	361	349	345	341	318	312	370

Impact of Replanting Intervention Allocation at Year 5											**F_5****
0	100	200	300	400	500	600	700	800	900	1000	
440	450	457	458	444	442	427	423	417	390	382	458

Scenario	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Scenario 1	0	100	300	300	300

F.3 Composite Index and Dynamic Programming Result for Simalungun District

Replanting Intervention allocation	Composite Index				
	Year 1 (2016)	Year 2 (2017)	Year 3 (2018)	Year 4 (2019)	Year 5 (2020)
0	79	80	74	73	73
100	81	83	80	80	82
200	83	83	78	80	80
300	85	85	80	79	79
400	79	79	74	73	73
500	79	80	74	73	73
600	79	80	74	73	73
700	79	80	74	73	73
800	79	80	74	73	73
900	79	80	74	73	73
1000	79	80	74	73	73

Total Allocation in Stage 1	Optimum Impact in Year 1 (F_1**)
0	79
100	81
200	83
300	85
400	79
500	79
600	79
700	79
800	79
900	79
1000	79

Total Allocation until Stage 2	F_1**	Impact of Replanting Intervention Allocation at Year 2											F_2**
		0	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**100**	
0	79	159											159
100	81	161	162										162
200	83	163	164	162									164
300	85	165	166	164	164								166
400	79	159	168	166	166	158							168
500	79	159	162	168	168	160	159						168
600	79	159	162	162	170	162	161	159					170
700	79	159	162	162	164	164	163	161	159				164
800	79	159	162	162	164	158	165	163	161	159			165
900	79	159	162	162	164	158	159	165	163	161	159		165
1000	79	159	162	162	164	158	159	159	165	163	161	159	165

Total Allocation until Stage 3	F_2**	Impact of Replanting Intervention Allocation at Year 3											F_3**
		0	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**100**	
0	159	233											233
100	162	236	239										239
200	164	238	242	237									242
300	166	240	244	240	239								244
400	168	242	246	242	242	233							246
500	168	242	248	244	244	236	233						248
600	170	244	248	246	246	238	236	233					248
700	164	238	250	246	248	240	238	236	233				250
800	165	239	244	248	248	242	240	238	236	233			248
900	165	239	245	242	250	242	242	240	238	236	233		250
1000	165	239	245	243	244	244	242	242	240	238	236	233	245

Total Allocation until Stage 4	F_3**	Impact of Replanting Intervention Allocation at Year 4											F_4**
		0	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**100**	
0	233	306											306
100	239	312	313										313
200	242	315	319	313									319
300	244	317	322	319	312								322
400	246	319	324	322	318	306							324
500	248	321	326	324	321	312	306						326
600	248	321	328	326	323	315	312	306					328
700	250	323	328	328	325	317	315	312	306				328
800	248	321	330	328	327	319	317	315	312	306			330
900	250	323	328	330	327	321	319	317	315	312	306		330
1000	245	318	330	328	329	321	321	319	317	315	312	306	330

Impact of Replanting Intervention Allocation at Year 5											F_5**
0	100	200	300	400	500	600	700	800	900	1000	
403	412	410	407	401	399	397	395	392	386	379	412

Scenario	Year 1	Year 2	Year 3	Year 4	Year 5
Scenario 1	300	300	100	200	100

F.4 Composite Index and Dynamic Programming Result for South Tapanuli District

Replanting Intervention allocation	Composite Index				
	Year 1 (2016)	Year 2 (2017)	Year 3 (2018)	Year 4 (2019)	Year 5 (2020)
0	75	69	65	64	61
100	75	71	67	68	66
200	76	72	70	71	70
300	77	74	72	74	75
400	78	76	75	78	79
500	79	77	78	82	84
600	79	79	80	85	89
700	80	80	83	89	93
800	81	82	85	92	91
900	82	84	88	96	95
1000	82	85	91	99	99

Total Allocation in Stage 1	Optimum Impact in Year 1 (F_1**)
0	75
100	75
200	76
300	77
400	78
500	79
600	79
700	80
800	81
900	82
1000	82

Total Allocation until Stage 2	F_1**	Impact of Replanting Intervention Allocation at Year 2											F_2**
		0	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**100**	
0	75	144											144
100	75	144	146										146
200	76	145	146	147									147
300	77	146	147	147	149								149
400	78	147	148	148	149	151							151
500	79	148	149	149	150	151	152						152
600	79	148	150	150	151	152	152	154					154
700	80	149	150	151	152	153	153	154	155				155
800	81	150	151	151	153	154	154	155	155	157			157
900	82	151	152	152	153	155	155	156	156	157	159		159
1000	82	151	153	153	154	155	156	157	157	158	159	160	160

Total Allocation until Stage 3	F_2**	Impact of Replanting Intervention Allocation at Year 3											F_3**
		0	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**100**	
0	144	209											209
100	146	211	211										211
200	147	212	213	214									214
300	149	214	214	216	216								216
400	151	216	216	217	218	219							219
500	152	217	218	219	219	221	222						222
600	154	219	219	221	221	222	224	224					224
700	155	220	221	222	223	224	225	226	227				227
800	157	222	222	224	224	226	227	227	229	229			229
900	159	224	224	225	226	227	229	229	230	231	232		232
1000	160	225	226	227	227	229	230	231	232	232	234	235	235

Total Allocation until Stage 4	F_3**	Impact of Replanting Intervention Allocation at Year 4											F_4**
		0	**100**	**200**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**100**	
0	209	273											273
100	211	275	277										277
200	214	278	279	280									280
300	216	280	282	282	283								283
400	219	283	284	285	285	287							287
500	222	286	287	287	288	289	291						291
600	224	288	290	290	290	292	293	294					294
700	227	291	292	293	293	294	296	296	298				298
800	229	293	295	295	296	297	298	299	300	301			301
900	232	296	297	298	298	300	301	301	303	303	305		305
1000	235	299	300	300	301	302	304	304	305	306	307	308	308

Impact of Replanting Intervention Allocation at Year 5											F_5**
0	100	200	300	400	500	600	700	800	900	1000	
369	371	371	373	373	375	376	376	371	372	372	376

Scenario	Year 1	Year 2	Year 3	Year 4	Year 5
Scenario 1	0	0	0	400	600
Scenario 2	0	0	0	300	700
Scenario 3	0	0	0	500	500

Appendix G Ethical Approval

Performance, Governance and Operations
Research & Innovation Service
Charles Thackrah Building
101 Clarendon Road
Leeds LS2 9LJ Tel: 0113 343 4873
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UNIVERSITY OF LEEDS

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**MaPS and Engineering joint Faculty Research Ethics Committee (MEEC FREC)
University of Leeds**

1 June 2018

Dear Muhammad

Title of study	**Development of Sustainable Supply Network in Indonesia Natural Rubber Industry**
Ethics reference	**MEEC 15-005**

I am pleased to inform you that the application listed above has been reviewed by the MaPS and Engineering joint Faculty Research Ethics Committee (MEEC FREC) and I can confirm a favourable ethical opinion as of the date of this letter. The following documentation was considered:

Document	*Version*	*Date*
MEEC 15-005 Muhammad Haikal Sitepu_Ethical Review Form Signed.doc	1	28/09/15
MEEC 15-005 Muhammad Haikal Sitepu_Fieldwork High Risk Assessment.pdf	1	28/09/15
MEEC 15-005 Muhammad Haikal Sitepu_Semi Structure Interview for Qualitative study.docx	1	28/09/15
MEEC 15-005 Muhammad Haikal Sitepu_Information sheet.docx	1	28/09/15
MEEC 15-005 Muhammad Haikal Sitepu_Consent Form.docx	1	28/09/15

Committee members made the following comments

Application section	**Comment**	**Response required/ amended application required/ for consideration**
A10 & C9	Given the small number of participants and the very specific sampling frame for the First Cycle (15 participants from 7 levels of the Indonesian rubber industry within a known geographical area) is it possible to guarantee anonymity/ confidentiality? Could some participants be identified by the nature of their response?	For consideration

Please notify the committee if you intend to make any amendments to the original research as submitted at date of this approval, including changes to recruitment methodology. All changes must receive ethical approval prior to implementation. The amendment form is available at http://ris.leeds.ac.uk/EthicsAmendment.

Please note: You are expected to keep a record of all your approved documentation, as well as documents such as sample consent forms, and other documents relating to the study. This should be kept in your study file, which should be readily available for audit purposes. You will be given a two week notice period if your project is to be audited. There is a checklist listing examples of documents to be kept which is available at http://ris.leeds.ac.uk/EthicsAudits.

We welcome feedback on your experience of the ethical review process and suggestions for improvement. Please email any comments to ResearchEthics@leeds.ac.uk.

Yours sincerely

Jennifer Blaikie
Senior Research Ethics Administrator, Research & Innovation Service
On behalf of Professor Gary Williamson, Chair, MEEC FREC

CC: Student's supervisor(s)