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Towards a framework for sustainable development planning in the Indonesian natural rubber industry supply network

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Abstract

Supply networks for natural resources such as rubber present significant opportunities to deliver global sustainability goals by reducing environmental, social and economic impacts of industrial activities. This research is using the Indonesian natural rubber industry as a case study. Early discussions with stakeholders highlighted a need for decision support tools to facilitate sustainability-related trade-offs in industry-wide and firm-level planning processes. The example used in this paper relates to rubber plantation replanting programmes and a three-way trade-off between customers' needs for a steady flow of rubber, an industry need to improve its environmental sustainability and rubber plantation owners' needs to maintain their financial sustainability which, in turn, influences social sustainability. An initial framework for sustainable development planning based on the case study and literature is proposed, and its use in the design of a computational simulation experiment using hybrid simulation models to predict the sustainability impacts of alternative replanting scenarios is reported.

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*Keywords:*sustainable development; sustainable supply network; sustainability assessment; natural rubber.

1. Introduction

Many countries have plentiful natural resources whose extraction is used to support economic growth is. However, environmental and social problems have accompanied this growth. Environmental problems include deforestation, land pollution from fertilizer and water pollution while social problems include human rights violations, poor working conditions and low wages. Together these factors have a detrimental impact on the environmental and social sustainability of the supply networks that convert natural resources into saleable products.

As a result of this, stakeholders who play important roles in society such as governments, regulators, community activists and non-governmental organizations, are pressurizing companies to improve the sustainability of their products and supply chains. Sustainable development is the means by which such improvements can be delivered [1]. The first widely accepted definition of sustainable development is found in the Brundtland report [2]: 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs'. Three dimensions of sustainable development, the triple bottom line (3BL) concept (profit, people and planet), were introduced by Elkington [3]. Pressure for change coupled with the emergence of sustainable development have triggered questions surrounding how best to include sustainable development goals in the strategic planning of supply networks.

Indonesia provides around 30% of the world's natural rubber. As a result, fluctuations in the capacity of Indonesian rubber plantations present a significant risk to the world's rubber supply. Early discussions with Indonesian rubber industry stakeholders highlighted a need for decision support

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tools to facilitate sustainability-related trade-offs in industry-wide and firm-level planning processes. This paper introduces the development of a framework for combining these complex perspectives when making decisions.

The case study used in this paper relates to rubber plantation replanting programmes and a three-way trade-off between customers' needs for a steady flow of rubber, an industry need to improve its environmental sustainability and rubber plantation owners' needs to maintain their financial sustainability which, in turn, influences social sustainability. An initial framework for sustainable development planning based on the case study and a review of literature is proposed, and its use in the design of a computer simulation experiment reported. The simulation used a hybrid approach that included both system dynamics and agent-based models to predict sustainability impacts of alternative replanting scenarios.

A review of the literature is provided in Section 2. This is followed, in Section 3, by the description of a case study based on the Indonesian natural rubber industry. The framework that was used to integrate the simulation models is introduced in Section 4 and, in Section 5, results from the hybrid simulation model are presented. Finally, in Section 6, conclusions and future work are discussed.

2. Literature Review: Sustainable Supply Networks

This section reviews key issues in planning for the development of sustainable supply networks. It begins, in Section 2.1, with a review of current models for assessing sustainable development in supply networks. This is followed, in Section 2.2, by a review of the use of computer simulation tools in sustainable development planning, with a focus on hybrid simulation models which combine system dynamics and agent based model simulation models.

2.1. Sustainability Assessment

A significant challenge in sustainable development planning lies in assessing the sustainability of different options. A range of tools for measuring and quantifiying sustainability and tools for sustainability impact assessment have emerged to address this problem [4]. Hassini et al [1] provide a review of these tools and identify a need for a composite indicator that can be used to assess different dimensions of sustainability practices implemented by key players in the supply network. Hassini et al's framework covers the three dimensions of sustainability. Chardine-Baumann and Botta Genoulaz [5] propose a model to assess the impact of supply chain management practices, consisting of economic, environmental and social dimensions. In this model, impacts of practices are presented in terms of positive or negative impacts based on relationships between practices and sustainability fields in literature [5]. However, what constitutes a positive or negative impact is difficult to determine especially when, for example, the impact of a given intervention varies over time.

There are a number of other models available in the literature but the availability of data to populate these models is limited. For example, Accorsi et al [6] report a detailed study on the collection of data in food supply chains. The research reported in this paper explored the feasibility of using computer simulation tools to generate such data. Software simulation models present significant promise for sustainability assessment [7]. For example, they can be used to explore impacts of development plans and decisions such as material flow across networks, economic sustainability of key players within the network and environmental sustainability. However, as with any computer model, simulation models need to be calibrated, validated and verified [8]. With appropriate safeguards, however, simulation tools have the potential to enhance decision making processes by presenting data from activities in the network at a network level [9].

2.2. Hybrid Simulation Models

Supply networks are complex systems that consist of different stages, tiers, and types of organizations, activities, interactions and relationships between organizations inside the network [10], [11]. There is a wide literature on the use of simulation models in supply chain logistics where the focus is on the flow of materials and information across the network. When making decisions related to sustainable development, however, decision makers need richer visualisations that include both process-related flows and consequences of the behaviours of individual stakeholders. Hybrid simulation models present significant promise to capture this complexity and generate insights to support planning decisions.

However, the need for hybrid simulation model triggers a question regarding the best combination of different models and how this might be matched with the needs of decision makers. According to Borshcev [12], the combination of modelling method is influenced by nature of a system that want to capture, boundary of modelling and objective of modelling. Different kinds of simulation model are suited to particular kinds of problem. For example system dynamics-based models are well suited to situations where interrelationships between entities inside the system are important. On the other hand, agent based models are better suited to understanding interactions between agents whose individual behaviours are not directly related to each other. A hybrid approach was selected for use in this research because rubber replanting is a process that is well modelled by system dynamics whilst interactions between key players inside the supply network are more aligned with agent based models. The combination of system dynamics and agent based simulation models is one that presents complementary conditions between the two methods [13]. System dynamics is well-suited for modelling a system at an aggregate level while agent based methods are better for modelling systems at an individual level (agent).

Verburg [14] used hybrid modelling to capture changes in land use. System dynamics was used to capture causal links between erosion/sedimentation processes with land use change while agent based modelling was employed to capture decision making processes of land owners. Similarly, Gaube et al [15] developed a carbon balance system in Austria region which had been influenced by behaviour of farmers and activity of farmers. Agent based modelling was used to capture the behaviour of farmers while system dynamics was used to simulate carbon balance system. In another application domain, Kieckhafer et al [16] used hybrid modelling to support decision making in vehicle manufacturing. Agent based model was used to capture decision of customers which influenced by models and technology. The decision of customer then influenced vehicle manufacturing's decision which was modelled using system dynamics.

Hybrid simulation approaches present significant opportunities to support decision making processes. This paper reports an implementation of hybrid modelling in the area of sustainable supply network planning in the Indonesian natural rubber industry.

3. Case Study

Natural rubber contributed 5.94% of total Indonesian Gross Domestic Product (GDP) in 2010, increased significantly from 2.1% of GDP in 2001. This was primarily achieved by increases in the production (and so yield per hectare) and price of rubber. Figure 1 illustrates the natural rubber supply network in Indonesia, based on information from the Indonesian Ministries of Industry, the Indonesian Ministries of Agriculture, the Indonesian Rubber Association and Indonesian Statistics Agency.

Approximately 85% of rubber plantations in Indonesia are owned by smallholders, produce low quality natural rubber, and have low productivity, technology adoption, and funding to cultivate and maintain their plantations when compared with other rubber producing countries including Thailand and Malaysia. This limits the ability of smallholders to adapt to volatile prices in the rubber market. Many smallholders therefore stop planting rubber and change to other crops such as palm oil, soybean, and cacao. Moreover, financial and technical constraints mean that smallholders have limited power to plan replanting programmes. These conditions have affected the rubber supply from Indonesia.

The Indonesian government has allocated funds to support rubber tree replanting with a view to achieving a sustainable supply through its natural rubber supply network. Some of the funding has been allocated to help the smallholders replant their plantations. Currently, allocation of land for replanting has not considered wider sustainability impacts of replanting in a systematic way. There are three reasons why the allocation of replanting needs to consider sustainability impact of replanting. Firstly, replanting will influence current and future rubber supply levels. Secondly, smallholders need significant capital to perform replanting while at the same time losing income while the unproductive plantation re-grows (economic and social impact). Finally, replanting causes environmental impact when the implemented using inappropriate methods such as burning the land.

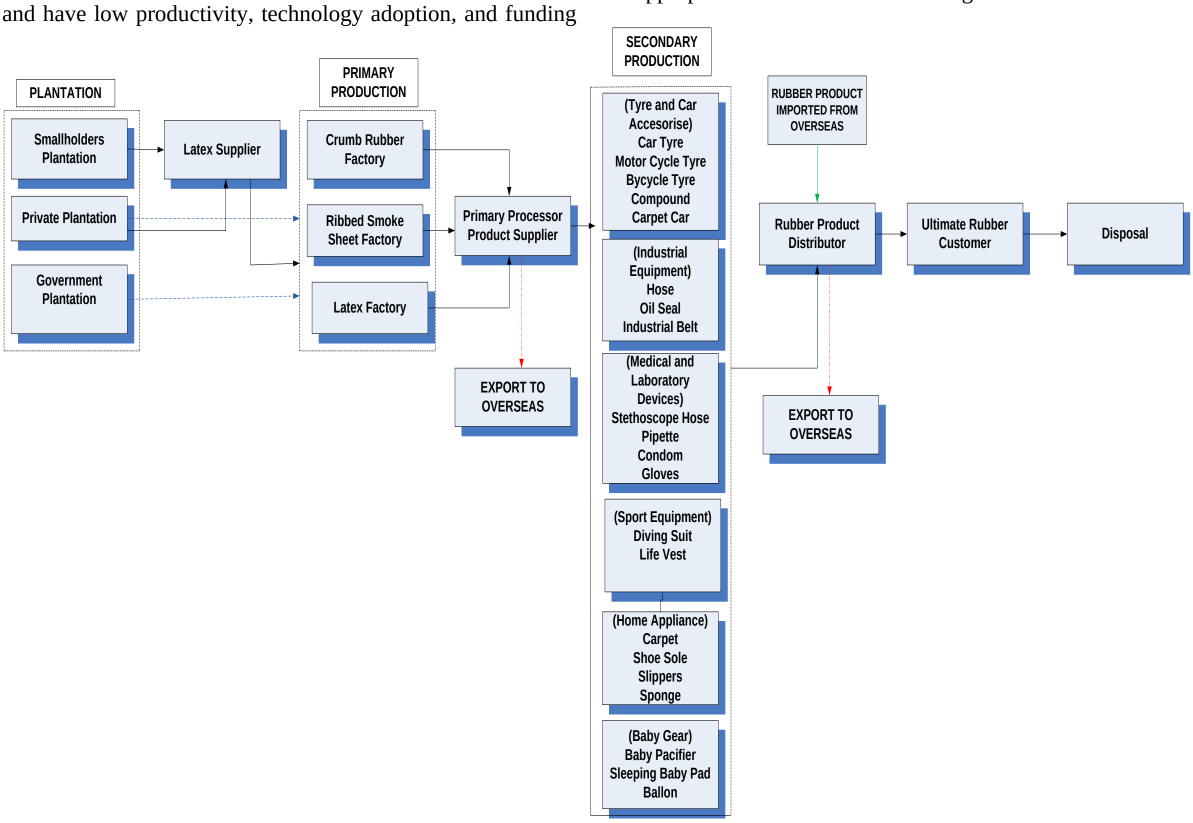

Fig. 1. Indonesia Natural Rubber Industry Supply Network

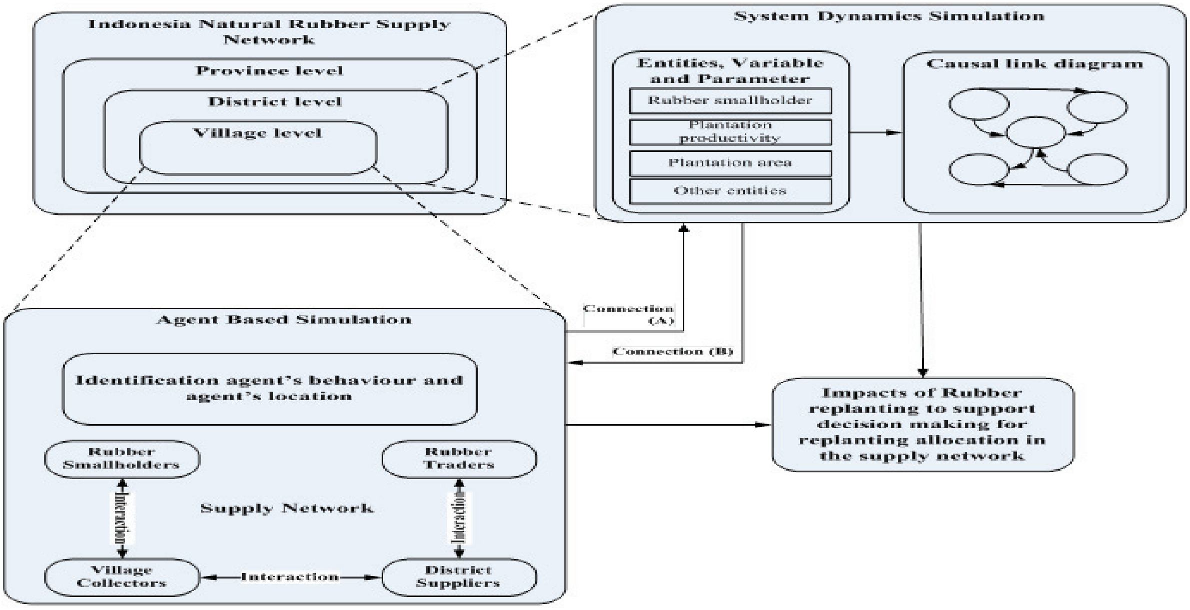

Fig. 2. Sustainable Development Planning Framework (connection A refers to simulation results from the agent based model feeding into the system dynamics model and connection B refers to system dynamics parameters that will be used in the agent based simulation)

4. Sustainable Development Planning Framework

Based on the literature review and case study, a framework for sustainable development planning was constructed (see Figure 2). The purpose of the framework is to identify different players in the network, relationships between players and inform the selection of simulation models for use in assessing the impact of alternative rubber replanting strategies in Indonesia natural rubber supply network.

The framework accommodates four levels of the network: whole network, province, district and village. The network in this paper is the Indonesia natural rubber supply network. The simulation models reported in this paper focussed on the district and village levels of the network. At the district level, the supply network is simulated using system dynamics. The ability of system dynamics to capture aggregate value is used to provide a high level view of the supply network. At a village level, the supply network is simulated using agent based methods. The ability of agent based methods to capture behaviours of key players and their interactions is used to provide low (individual) level perspectives on the supply network.

The framework shows a connection between the system dynamics and agent based simulation. This connection was proposed based on [17]. Parameters in the system dynamics models are to be used in agent based simulation while emergent behaviour of agents are used as parameters in system dynamics simulation. Simulation result from both simulation methods is planned to be used for supporting decision maker in allocating rubber replanting accross the supply network.

5. Simulation Method and Result

A challenge for the Indonesia natural rubber industry lies in understanding how to implement replanting programmes effectively and maintain the long-term sustainability of its rubber supply. The International Rubber Study Group (IRSG, http://www.rubberstudy.com/) in Sustainable Natural Rubber Initiative (SNR-i) has highlighted the management of replanting activities as being critical to sustain the production of natural rubber. Hence, an assessment model is required to evaluate replanting activities and their impact on the performance of the natural rubber supply network. The simulation model reported in this section was designed to assess the impact of current replanting plans with respect to natural rubber production volumes, rubber plantation areas and the economic situations of plantations and other key players. The output of simulation is intended to provide support for decisions related to different replanting scenarios.

As shown in figure 2, the Indonesia natural rubber supply network was used to determine a scope for the hybrid simulation model. In addition, it was used to construct a conceptual model for the system dynamics simulation and define agent behaviours for the agent based model. The scope of the simulation is limited to two stages in the Indonesia natural rubber supply network: the plantation and latex supplier tiers. Three key players in the plantation tier are smallholder plantations, private plantations and state owned plantations. At the latex supplier tier, there are three further key players: village collectors, district suppliers (middlemen) and traders.

The main function of the supply network in these stages is to provide latex as raw material for primary processors who are geographically scattered across the province. System dynamics focused on building understanding of links between entities at district level and presenting result of simulation for district level. On other hand, the agent based simulation focused on determining interactions between key players (agents), representing the supply network as a group of independent actors and presenting results at a village level.

As stated earlier, data used in this simulation came from the Indonesia natural rubber industry in the North Sumatera Province. This Province is the location of significant players, including rubber plantations, latex suppliers, and primary and secondary rubber processors. Data used in this simulation was taken from one district in North Sumatera Province which is Langkat District.

5.1. System Dynamics Simulation

The system dynamics simulation model was built by defining relationships between entities in the Indonesia natural rubber supply network. Based on the scope of simulation, entities of the system were categorized as rubber smallholder, private plantation, state-owned plantation, land area, latex (in slab, lump, sit, less concentrate latex), stepper, village collector, district supplier (middleman) and trader. Relationships between entities were defined using a system dynamic flow diagram. Parameters that influenced value for every entity in the system were then defined. For example, the total number of rubber smallholders is influenced by the growth rate of new smallholders, the bankruptcy rate of current smallholders and the rate at which individual smallholders change their plantations to grow other crops. Finally, values for each parameter were specified based on real values from the Langkat District and on policy or planning performed in the district. For instance, the value of the start-up rate for new rubber smallholders was based on data from the government replanting program where the government provides land and start-up funding.

Simulation runs were started by setting scenarios of replanting. Rubber replanting is implemented by rubber smallholders, private companies and state owned companies. Scenario of replanting were different for each of these stakeholders. Figure 3 shows the replanting scenarios for these different players.

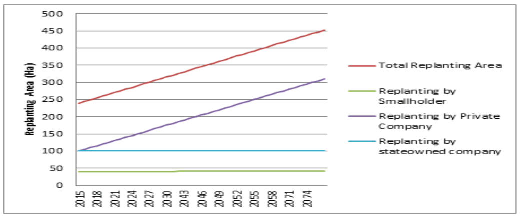

Fig. 3. Initial Replanting Scenarios from Different Players (inputs to the systems dynamics simulations)

Rubber production in the Langkat district was dominated by plantations with trees between 15-20 years old. As a result, the simulation model predicted significant reduction of rubber supply and, productive area of rubber plantation in next 5 years (see Figure 4). This occurred due to an imbalance in the age of plantations in the Langkat district. Furthermore, in the short term, replanting increases the non-productive plantation area for approximately five years after trees have been planted, so exacerbating the impact on latex and, as a result, rubber supply.

The reduction of plantation productivity has a multiplier effect which decreases the production of latex. The productivity of the plantations in the third stage (year 15-20) fell significantly and, in phase 4 (year 20-25), increased significantly over the succeeding 5 years due to the planned establishment of many new plantations in phase 3 starting production in phase 4. This result indicated that the initial replanting scenarios have been likely to fail in sustaining the future natural rubber supply. The production of latex from rubber plantations is displayed in figure 4.

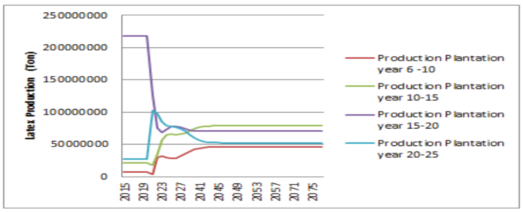

Fig. 4. Impact of Initial Replanting Scenarios into Future Latex Production (output of the systems dynamics simulations)

5.2. Agent Based Model

Agent based simulation was employed to capture the actions and decision making performed by agents at an individual level, which cannot be captured in a system dynamics simulation. The first step in this simulation was to select the agents to be included in the model. Four agents were selected: rubber plantation, village collector, district supplier and trader. The physical location of each agent was predicted using a GIS (Global Information System) database which consisted of longitude and latituted of each agent's position.

The next step was to specify the behaviours of each agent in the model. The behaviour of rubber smallholders is to produce latex and request its collection by a village collector. A given village collector can receive collection requests from more than one rubber smallholder. If capacity in the warehouse owned by village collector is available then the village collector will send transportation to collect latex from the rubber smallholder. Village collectors also contact district suppliers to inform them of availability of latex when the stock in their warehouse reaches a certain (maximum) level. The district suppliers receive latex from village collectors through a push system where the amount that can be received from different village collectors is unlimited.

At a district supplier and trader level, when capacity of the warehouse reaches a certain level, the district supplier offers latex to one or more traders. The decision of a trader to accept an offer of latex is based on the capacity of their warehouse. If availability of warehouse capacity is larger than the amount of latex offered by the district supplier then the trader can accept the latex from the district supplier. Furthermore, every trader has a plan to supply latex into different primary processors.

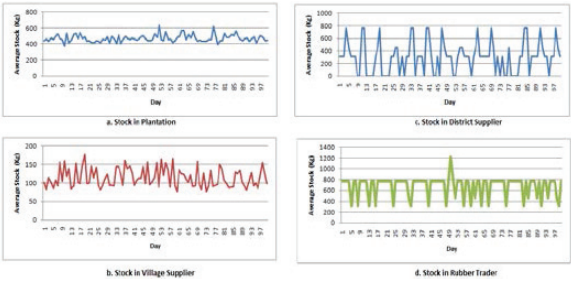

Fig. 5. Average Level of Stock from Plantations and Different Suppliers (output of the agent based simulation)

The database of agents consisted of 30 plantations, five village suppliers, two district suppliers and two rubber traders. In the database, every agent had a GIS position which had been randomly generated across the Langkat district territory. For the agent based model simulation, it was necessary to observe material stock levels through the network. Four types of stock were observed during the simulation: stock in rubber traders, stock in district suppliers, stock in village suppliers and stock in plantations. Figure 5 shows the fluctuation of stock level from plantations and different suppliers.

The simulation modelling reported in this section shows how hybrid simulation models can provide useful insights for decision makers involved in the planning of sustainable rubber supply networks. Current work is exploring the integration of the two models so that, for example, the impact of replanting decisions on future stock levels can be explored.

6. Conclusion and Future Work

A review of current research on sustainable supply networks was used to inform the definition of a sustainable development planning framework. The Indonesian natural rubber industry was used to define the scope for hybrid simulation models that include both system dynamics, for process driven aspects, agent based simulation for consequences of individual behaviours. However, the proposed framework needs to be validated and verified by conducting empirical research.

The simulation experiments presented show to feasibility of simulation models as a sustainability assessment tool for use in assessing the impact of replanting scenarios in rubber production and plantation areas in the future. These results can be used to support decision making related to the allocation of rubber replanting for different districts in one province in Indonesia. These hybrid simulation models are important element in the proposed framework.

The research reported in this paper focuses on the development of integrated planning and assessment tools in natural rubber supply networks. Future work on a sustainability assessment tool will be focused on how to connect system dynamics and agent based simulations, and on development of the planning framework. Moreover, validation and verification is one important part of future work in order to get reliable results from the simulation models. More approaches are required to support the framework such as trade off tools to determine the optimum replanting scenarios.

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