Increasing Liquid Fuel Self-sufficiency in Indonesia through Utilization of Marginal Land and Appropriate Technology for Biofuel Production

A thesis presented in partial fulfilment of the requirements for the degree of

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ABSTRACT

This study proposed a strategy for increasing self-sufficiency of liquid fuel in Indonesia. The novel approach not previously undertaken was to integrate the utilization of marginal land with innovative technology for drop-in biofuel (DBF) production. The strategy involves interdependent relationships, so a systems dynamics modelling approach was applied. The assessments generally cover the national scope, but also specifically used Sumba Island as a case study around the marginal land issue.

From a number of potential energy crops considered for growing on Sumba Island, *Pongamia pinnata* was selected. Metal soap decarboxylation was chosen as the preferable conversion technology for this oil crop, even though it has not yet reached full commersialisation.

A simulation framework was developed to explain the intrinsic interrelationship between elements. These comprised the preparation of feedstock from marginal land, preparation of more appropriate conversion technology, a liquid biofuel supply system, and liquid fuel import demands. A delay in any of the elements causes a delay in DBF uptake, and thus time becomes a crucial factor. Considering the time factor, this study assessed the political dimension of sustainability, which is lacking in other bioenergy studies.

A model, *Assessment Tool of Biofuel Strategy through Utilization of Marginal Land and Innovation in Conversion Technology* (ABMIC) was developed to test the strategy outcomes in some priority sustainability indicators. The model consists of ten sub-models containing two feedback loops invented in this study: a) between the "sense of urgency for action by the President" (SU) and liquid biofuel supply and demand; and b) between the conventional biofuel production from palm oil and the DBF production. The ABMIC model was tested and validated for structural validity, behaviour validity, and model usefulness.

The results from scenario-based simulations confirmed that a systems dynamics approach was suitable for assessing the strategy. It supported the hypothesis that a political element, namely SU level, critically affects the success in implementing a liquid biofuel strategy through marginal land use and conversion technology innovation to increase liquid fuel self-sufficiency, which in turn influences the political element itself. An increase in SU level leads to a significant increase in liquid fuel self-sufficiency, foreign exchange saving, gross regional domestic product, and CO_2 emissions reduction. SU should be sustained by maximizing future vision intervention. With modifications, the SU structure could be applied in non-biofuel sectors.

Finally, this study outlines opportunities for further research to improve the model including through disaggregation, endogenizing variables, building functions of effects between variables, improving the variable quantifications, and further exploration of the variables.

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LIST OF ABBREVIATIONS

ABMIC	Assessment Tool of Biofuel Strategy through Utilization of Marginal Land and Innovation in Conversion Technology
bbl	Barrel
BEV	Battery electric vehicles
BOT	Balance of trade
BOV	Balance of volume
BPDPKS	*Badan Pengelola Dana Perkebunan Kelapa Sawit* Agency for Collection and Use of Oil Palm Plantation Fund
BPN	*Badan Pertanahan Nasional* National Land Agency
CAD	Current account deficit
CBS	Climate benefit scenario
CPO	Crude palm oil
CRC	Crop rotation cycle
DBF	Drop-in biofuel
DMO	Domestic market obligation
DPD	*Dewan Perwakilan Daerah* Regional Representative Council
DPR	*Dewan Perwakilan Rakyat* House of Representatives
ETI	Energy-technology innovation
FAME	Fatty acid methyl esters
FP	Full Pressure
FV	Full Vision
GHG	Greenhouse gases
Gl	Giga litres
GRDP	Gross regional domestic product
GWh	Giga watt-hours
IEA	International Energy Agency
ITB	Institut Teknologi Bandung
IV	Iodine value / Initial value
KOH	Potassium hydroxide
LPG	Liquefied petroleum gas
LV	Low Vision

Mboe	Thousand of barrels of oil equivalent
MEMR	Ministry / Minister of Energy and Mineral Resources
Mha	Mega hectare
MJ	Mega joule
MMbbl	Million barrels
MPR	*Majelis Permusyawaratan Rakyat* People's Consultative Assembly
MV	Medium Vision
MW	Mega watt
NDC	Nationally Determined Contributions
NGO	Non-governmental organization
OBS	Oil feedstock benefit scenario
PPO	Pure plant oil
SII	Sumba Iconic Island
SU	Sense of urgency by the Indonesian President
t	ton
TOS	Trade-off scenario

CHAPTER 1
INTRODUCTION

1.1 Geographic, economic and political profile of Indonesia

1.1.1 Geographic

Indonesia is a large archipelago with 16,056 islands and around 260 million population which is distributed on 1.9 million km^2 area. It is located between 6^0 04' 30" North Latitude - 11^0 00' 36" South Latitude and 94^0 58' 21" – 141^0 01' 10" East Longitude, that has tropical climate with rainy seasons in October-January and dry seasons in April-September. (BPS, 2018b)

1.1.2 Political

Indonesian political system is based on Trias Politica principle that distinguishes legislative, executive, and judicative power (Indonesia, 2002). Structure of political administration for legislative and executive institutions is depicted in Fig. 1.1

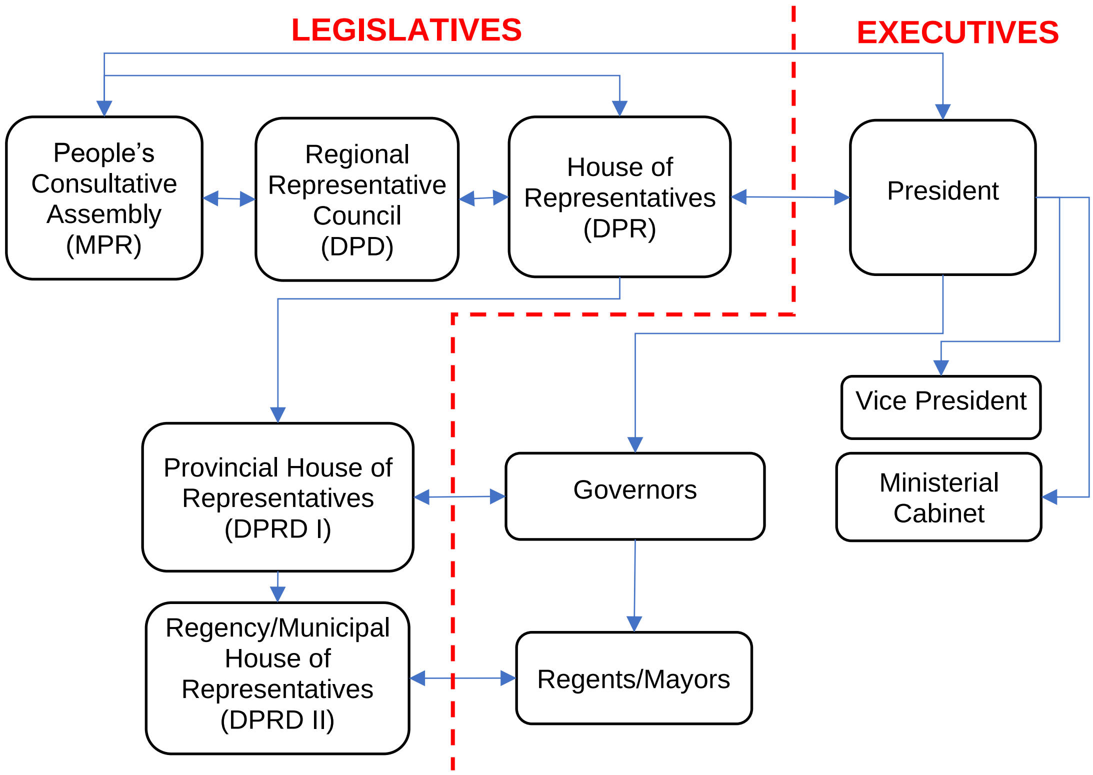


Fig. 1.1 Structure of political administration for legislative and executive institutions in Indonesia (BPS (2018b); Indonesia (2002))

At national level, executive power is held by President. Legislative institutions consist of The People's Consultative Assembly (MPR), The House of Representatives (DPR), and The Regional Representative Council (DPD).

President's rights include proposing a bill to DPR, passing the law and establishing a governmental regulation to implement the law. In implementing the law, President is assisted by a Vice President and cabinet ministers.

MPR consist of DPR and DPD and has rights for amending and establishing The 1945 Constitution of The Republic of Indonesia. DPR's rights includes drafting a bill through discussions with the President to reach an agreement. DPD members are non-partisans who represent each province. DPD can propose a bill to DPR and supervise the law implementation that relates to certain subjects including management of natural resources and other economic resources, and state budget.

At local levels, local governments do their own governance based on full autonomy on any areas except those are regulated by laws as the federal government's authority such as tax, education and religion affairs. They have local House of Representatives (DPRD I at provincial level or DPRD II at regency/municipal level) who have rights for establishing regional government regulations and other regulations for the law implementation. In pressing situation, DPRD I and DPRD II can establish a local governmental regulation to replace a law.

In implementation of biofuel program, President gives an instruction (could be through a Presidential Instruction) to relevant ministers that includes the Minister of Energy and Mineral Resources. Based on evaluation, the President satisfactory on the progress would determine the ministers' continuation in their job.

As an example, in 2005 a Presidential Instruction was enacted to be followed up by relevant ministers that include Minister of Energy and Mineral Resources (MEMR). Then, in 2008, MEMR launched an MEMR Regulation containing biofuel target mandatory. The MEMR regulation was revised in 2013 and 2015 in terms of the concentration level and the reward and penalties.

The success of biofuel implementation which is multisectoral would be determined by the level of sense of urgency by the President (SU). Urgency is defined as "the quality of being very important and needing attention immediately" (CambrigeDictionary, 2019). The higher SU would trigger more and better involvement of related ministers.

SU is subjective and can easily change by existing situations. To maintain a good SU level, an anticipative driver is required, such as a future vision for the nation. Vision (view of the future) is defined as “the ability to imagine how a country, society, industry, etc, could develop in the future and to plan for this” (CambridgeDictionary, 2019).

1.1.3 Economic

in 2017, Indonesian economic growth reached 5.1% and the GDP per capita was IDR 51.9

million. The main economic sectors are processing industries, trading, construction, and agriculture (BPS, 2018b). In energy sector, crude oil resources is declining, while renewable energy including biomass abundant.

1.2 Strategy for sustainable liquid biofuel development

Liquid biofuel is a liquid fuel that is generated from biomass. It is the only non-fossil energy available in liquid form that can be used to decarbonise the transport sector. As well as in developed countries (RAE, 2017), biofuels are projected to play a significant role in the long term in developing countries including Indonesia (Oberman, Dobbs, Budiman, Thompson, & Rosse, 2012).

However, liquid biofuel is perceived in the sustainability context to have some main concerns including conflicts with food crop production and greenhouse gases (GHG) net emission from land use. A potential strategy to cope with these issues is using marginal land to grow non-edible energy crops as has been widely studied and tried in several countries.

“Marginal” land is a land area which soil condition such as the fertility and water are inadequate to sustain cultivation of an expected crop, due to the degradation process. In comparison, “degraded” land is a land area that has lost part or whole of its production capacity (UNEP, 2007), that makes the land being in a degradation process to become marginal land (Wiegmann, Hennenberg, & Fritsche, 2008). It means that a land categorised marginal for a certain crop might not be marginal for another crop.

Potential benefits from utilizing marginal land for growing biomass feedstock are significant, such as energy security, economic growth and GHG mitigation:

- Energy security

  Oilseeds and wood-fuels produced from marginal land will increase the availability of biomass feedstock for liquid biofuels as well as bioelectricity and bioheat that will support energy security.

  Liquid fuel self-sufficiency of a country indicates the country's ability to fulfil liquid fuel demand domestically using its own feedstock resources. The world demand for petroleum fuels is projected to rise from 5,049 Gl (87 Mboe) per day in 2010 to 6,906 Gl (119 Mboe) per day in 2040 (EIA, 2014), mainly by developing countries in Asia and the Middle East. Indonesia's liquid fuel demand is projected to reach 260 Gl which the halved needs to be imported (BPPT, 2018).

  By increasing biomass feedstock quantity through marginal land use, energy security enhancement is affected through a more controllable feedstock price, especially if the land is owned and well managed by the government. This is of great importance as feedstock cost usually dominates the total production cost of liquid biofuels. In light of the fact that renewable sources for liquid fuels are only from biomass, it is essential to prepare the biofuel supply in a sustainable way.

- Economic growth

  Utilizing marginal land for bioenergy feedstock can improve the economy at the local level as well as national level. In term of food crop purpose, which is considered more important than energy use for human well-being, marginal land can be categorized as unproductive land due to its economic infeasibility to grow food crop, so that earning revenue through energy crop grown there can improve the local economy.

  At the national level, it can substantially improve national economic growth by reducing dependence on imported oil. To exemplify, between 1973 and 1979 the combined economic shocks from world price increases in crude oil caused the oil-importing developing countries lost up to 22% of their annual GDP growth (Chichilnisky, 1985).

  Indonesia economic growth has been relatively high compared to most other countries in the last decade. It is clear that in order to minimize importation burden which is detrimental to its economic growth, Indonesia should do appropriate strategy using its potential such as liquid biofuel utilization.

- GHG mitigation

  As mentioned earlier, one of the sustainability indicators is the capability for decreasing greenhouse gas (GHG) level in the atmosphere. This can be carried out through marginal land use due to lower or zero carbon stock compared to the level in the land's initial condition.

  To combat global warming, the Paris Climate Agreement from the 21st United Nations Framework Convention on Climate Change Conference of the Parties (UNFCCC COP 21) was established in December 2015 and since then has been ratified by 185 parties including Indonesia (UNFCCC, 2019). It set an objective to limit the atmospheric temperature increase to be below 2°C compared to the pre-industrial era before the end of this century (UN, 2015). In achieving the target, it is critical to speed up low carbon energy utilization as one of the most reasonable efforts, especially for Indonesia that has high fossil fuel share in its energy mix whereas renewable fuel resources are abundant.

Thus, producing biomass through marginal land use can simultaneously handle multiple important issues, namely economic growth, energy security and GHG mitigation. However, its implementation success is dependent on several factors, including strategic choice of right energy crop before cultivation which is crucial because it will be impacting for up to decades.

Another important issue for increasing liquid fuel self-sufficiency in Indonesia is the fuel characteristics. Liquid biofuel products that are currently available in the commercial market have properties that cause limitation for being mixed with petroleum fuels in the existing engines. To allow higher utilization and its benefits, it is necessary to implement appropriate technology for liquid biofuel products that have similar properties to petroleum fuels. The appropriate conversion technology used to produce the biofuels from the biomass feedstock should be strategically determined.

1.3 The need for an integrated and modelling approach

Utilizing marginal land normally takes several years since the identification and preparation of the available area until the crop is planted and then harvested. During the period of land preparation and plantation growth, liquid fuel demand keeps increasing and thus the requirement of liquid biofuel that can be used at high concentration, such as drop-in biofuel (DBF) (Chapter 5) which has equivalent characteristics with petroleum fuels. As the development of the appropriate conversion technology will also take time, it is necessary to integrate the assessment of the preparation of marginal land as well as the appropriate technology to assess when both preparations are ready for starting the commercial DBF production to realize a more sustainable liquid biofuel development.

Dealing with sustainability involves interrelated aspects which cover interdependent elements. This creates complexity in systems of the proposed integrated liquid biofuel strategies. Many studies on liquid biofuel group sustainability dimensions into economic, environmental and social aspects (GBEP, 2011). However, sustainability can have four criteria to be met; ecological, economic, social and political (Sachs (1999) in Musango (2012)). There is also a broader definition of sustainability by the Massachusets Institute of Technology as the interdependent systems of economy, society, politics, the environment, and the individual (MIT, 2015).

Musango (2012) stated that political sustainability issues as in Sachs (1999) classification are often included in social sustainability. It is hard to find any research on how political sustainability interrelates with other elements of sustainability, particularly in the energy sector. On the other hand, (it is argued in this thesis that) in many cases, including bioenergy development in Indonesia, the political dimension plays a critical role. Therefore, it was assessed explicitly here to better understand the systems and help with providing more effective solutions.

In addressing policy-related issues in the proposed strategy for liquid biofuel development, this study covers multidisciplinary subjects including energy, economy, environment, social, biofuel production technology, management, and politics that have relationships to one another. Also, due to its cross-sectoral nature, policy formulation on bioenergy in Indonesia involves multi-sectoral government and non-government institutions at various regional levels. This issue, plus the limited resources and knowledge available, have become major challenges in developing this young sector. Therefore, assessment on this study needs to be carried out in an integrated fashion.

The complex characteristics of the problem due to the existence of feedback loops make it challenging to understand the nature and the significant interrelationships of the systems without the aid of a computer model (Maani and Cavana (2007); Sterman

(2000)). Building a simulation model can be an important tool in policy formulation or analysis for liquid biofuel in Indonesia which so far has not been utilised when establishing existing policies and measures.

The system dynamics approach has been recognized as capable of performing computer modelling of policy which commonly consists of feedback loops. System dynamics modelling can assist with understanding interconnections, identifying significant variables or loops, trade-offs between sectors, and short versus long term impacts in the system. These all will help with improving the real-world systems (Maani and Cavana (2007); Sterman (2000)).

1.4 Research Hypothesis, Aim and Objectives

The problem identified here is that Indonesia's indigenous oil reserves are dwindling; importing more petroleum products in future to meet the growing demand will lead to greater insecurity of energy supply; and as the transport sector continues to grow, combustion of petroleum-based fuels will result in higher greenhouse gas emissions making it more difficult for Indonesia to meet its mitigation targets.

To provide a solution to the problem, this thesis proposes an integrated strategy of utilisation of marginal land and appropriate technology for biofuel production to increase liquid fuel self-sufficiency in fulfilling its long-term liquid fuel demand more sustainably. To support the implementation of executing the proposed strategy, it is necessary to do an integrated assessment using a modelling approach by which the policymakers understand the nature of the problem and all the involved systems.

This research hypothesizes that if liquid biofuels are produced in Indonesia as low-carbon alternatives to petroleum fuels, a political element will critically affect the success of implementing a liquid biofuel strategy that includes marginal land use and conversion technology innovation to increase liquid fuel self-sufficiency, which in turn influences the political element itself.

The overall aim of this research is to understand better how policy implementation could affect liquid biofuel implementation and thus liquid fuel self-sufficiency, through utilization of marginal land and innovation in conversion technology, and vice versa.

An assessment tool of the strategy to increase liquid fuel self-sufficiency in Indonesia was developed through system dynamics modelling. The model developed as part of the study was utilized for providing policy analysis and recommendation to improve liquid biofuel development through the proposed strategy. Some actual specific issues related to sustainable liquid biofuel implementation were addressed within an integrated framework including:

- how can the liquid biofuel supply through proposed strategy increase the liquid fuel self-sufficiency?
- how can the liquid biofuel supply (and delay) through the proposed strategy affect the economy? and
- how can the liquid biofuel supply through proposed strategy meet the GHG reduction pledge of Indonesia to the Paris Agreement?
- how can a policy or political aspect influence liquid fuel self-sufficiency as well as other impacts, with regards to a delay in executing the proposed strategy?

To achieve the research aim, seven specific objectives were established to:

(i) provide a review on liquid fuel supply and demand in Indonesia;

(ii) conceptualize a simulation framework for assessing the proposed strategy for increasing liquid fuel self-sufficiency in Indonesia;

(iii) analyse marginal land use for growing energy crop;

(iv) assess technology options for liquid biofuel production;

(v) provide a case study of the Indonesian island of Sumba as an example when developing the model;

(vi) build a system dynamics model for assessing the proposed strategy, and

(vii) develop and compare policy scenarios using the model.

To address the research objectives, the computer model was developed using data and information collected through literature analysis, focus-group discussions, and interviews at both national and local levels on the case study island. Stella® Architect software was used for the modelling work. Before building the system dynamics model, a set of analyses were conducted to determine a specific case that allows valuation of inputs to the models, for example choosing a preferable energy crop, the appropriate biofuel production technology, and the case study island.

To validate the model, a set of systematic and standardized methods was used that also made use of data and information collected through literature analysis, interviews, and personal communications with stakeholders that includes policymakers, landowners/farmers, and local experts.

1.5 Thesis structure and methodology approach

To address the research objectives, the thesis is structured as depicted in Fig. 1.1. *Chapter Two* presents an overview of Indonesia's liquid fuel supply and demand. This includes identification of priority indicators for liquid biofuel sustainability based on a vision for Indonesia which is strongly related to the political system and examines impacts of bioenergy using selected indicators.

Chapter Three proposes a simulation framework for developing a model as an assessment tool for the proposed liquid biofuel strategy. An analysis of the priority sustainability indicators from Chapter 2 leads to a conceptualization of marginal land use and future technology availability as an integrative strategy for more sustainable liquid biofuel implementation**.**

Chapter Four provides analysis on marginal land use for biomass feedstock production, particularly to assess the potential area of marginal land for bioenergy and a suitable energy crop for marginal land.

Chapter Five analyses existing and potential bioenergy conversion technologies, which are likely to become available in the future. It strategically proposes the most suitable one based on analysis result from Chapters 2 and 4.

Then *Chapter Six* assesses the characteristics of Sumba Island to show why it was chosen as a case study location for developing the model at the local level. This also shows the importance of local resource management.

Chapter Seven describes the development of the systems dynamics model that includes the process of data and information gathering, the explanation of the reference mode, and the design of the intervention.

Chapter Eight provides the modelling results and analysis. It presents a series of indicator variables that were used when modelling the policy scenarios. The results of different scenarios are compared to suggest what would be the policy implications and decisions needed in dealing with the problems that emerge from each scenario.

Finally, *Chapter Nine* summarises the study, presents the contributions and findings, discusses the model limitations, and identifies future research required for the improvement or advancement of the model.

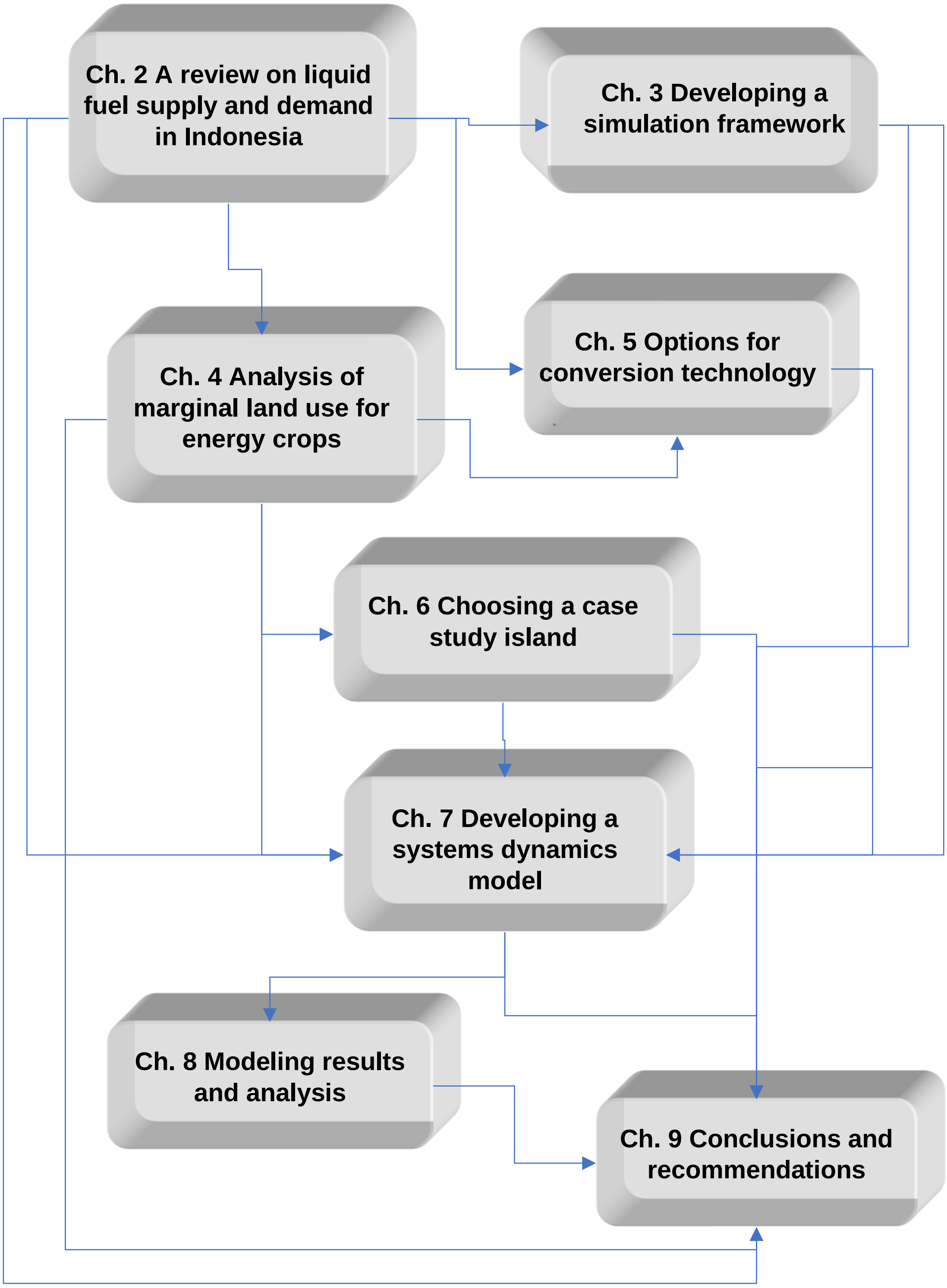


Fig. 1.2 Thesis structure and links between chapters

CHAPTER 2
A REVIEW OF LIQUID FUEL SUPPLY AND DEMAND IN INDONESIA

2.1 Introduction

This chapter reviews liquid fuel supply and demand in Indonesia. The demand for liquid fuel is increasing while domestic oil extraction and fuel production is declining. Therefore, liquid biofuel production and utilization will be crucial in future for supporting national energy security as well as the economy by improving the balance of trade.

Section 2.2 provides fundamentals of liquid biofuels; Section 2.3 describes historical data and projections of liquid biofuel supply and demand in Indonesia; Section 2.4 shows the interrelationship between the liquid biofuel development and the economic situation in Indonesia; then Section 2.5 discusses impacts of liquid biofuel production and use in Indonesia. Finally, Section 2.6 outlines the inputs from this chapter to be included in the system dynamics model developed in Chapter 7.

2.2 Fundamentals of liquid biofuel

Liquid fuels can be supplied from petroleum fuels as well as renewable biomass materials. Compared to gaseous or solid fuels, liquid fuels have some advantages such as ease of transport, storage and distribution, high energy density, and the low risk of explosion hazards (Soerawidjaja, 2001).

Liquid fuels have been widely used historically in transport, power plant, heating and industry sectors. Existing liquid petroleum fuels include (i) gas-oil (diesel fuel) and gasoline for land transport vehicles; (ii) heavy fuel oil for marine transport; diesel fuel for stationery engines in power plants and industries, and (iii) jet fuel for air transport. At the global level, liquid biofuels, the only form of renewable liquid fuel, have the potential to provide low-carbon fuel for marine and air transports as well as heavy-duty vehicles. In developing countries such as Indonesia, liquid fuels will still probably play a substantial role in future land transport due to the other alternatives such as gases and electricity not being fully commercially viable (BPPT, 2016).

In the long-term, liquid biofuels will still be key for various energy uses due to no other competitive alternative. In some developing countries including Indonesia, biofuels will be mostly irreplaceable in all sectors. At the global level, they will be vital for shipping, aviation, and heavy-duty vehicles (DECC (2012), IRENA (2017)).

Based on the chemical structure, liquid biofuel types include pure plant oil (PPO), fatty acid alkyl ester (FAAE, such as fatty acid methyl esters (FAME)), alcohols (such as methanol, ethanol, butanol), bio-oil, and biohydrocarbons. These biofuels, except for biohydrocarbons, are oxygenated and can partially substitute for petroleum fuels in most of the existing infrastructure. Oxygenated biofuels can partially substitute for petroleum fuels, while biohydrocarbons can be used at any concentration with petroleum fuels. The type of liquid biofuel used should enable a high concentration level in the mixture with petroleum fuels. One of the ways is by using drop-in biofuels (DBF) which have equivalent characteristics to gasoline, diesel, or jet fuel (Chapter 5). Oxygenated biofuels can play an important role in the transition to drop-in biofuel use.

2.2.1 Pure plant oils

PPO or straight vegetable oils are obtained from the original plant source through mechanical processes, such as pressing and degumming. The oil chemical properties are then similar as in the plant. PPO biofuels from oilseed rape, oil palms, sunflower etc. can be used for heating, cooking, and fuelling compression ignition engines with low rotation speeds such as used in ships, power plants, and industrial equipment. In the engines, PPO can be used as the whole substitute for fuel oil or as partial replacement of the diesel fuel.

2.2.2 Fatty acid alkyl esters

FAAE (termed biodiesel) are made from vegetable oils or animal fats mixed with alcohols through the trans-esterification process using an alkaline catalyst. Biodiesel is mostly used as fuel for diesel engines in vehicles and can also be used for engines with lower rotation speed. The maximum concentration of biodiesel mixed with diesel that is accepted for most vehicle engines without any modification is 20-30%, while in lower speed engines it is unlimited.

In Indonesia, a large biodiesel producer and user, biodiesel is produced from crude palm oil (CPO) and methanol. The cost of converting CPO to biodiesel in Indonesia is around USD 125/t (MEMR, 2016b). Using palm oil as biodiesel feedstock has raised environmental debates such as on deforestation issue which impact to the net CO_2 emissions reduction.

2.2.3 Alcohols

Alcohols can be produced via a chemical process as well as sugar fermentation. The common types of alcohol that have been used as liquid biofuels as substitutes for gasoline are methanol, ethanol, butanol and isobutanol.

Ethanol is the most widely utilized. The largest global producers and users of ethanol are the USA based on corn (maize) feedstock, and Brazil using sugarcane feedstock. In most gasoline engines, ethanol can be used up to 30% in a blend with gasoline. In flex-cars that have been available in some countries such as Brazil, it can be used as 100% pure ethanol which has energy value by 34% lower than gasoline (GNHCCC, 2017). Production costs were reported as USD cent 28 /l for sugarcane feedstock in Brazil and USD cent 45 /l for corn feedstock in the USA (Andreoli & Souza, 2007).

The key to economic production of bioethanol from sugarcane is the integrated production of sugar, ethanol through molasses, and bio-electricity from the residual bagasse. The problem of bioethanol use in Indonesia is that the feedstock such as molasses and cassava have been more economically attractive for non-energy use.

2.2.4 Bio-oil

Bio-oil is a liquid product resulting from the thermolysis (or pyrolysis) of ligno-cellulosic biomass. It contains oxygenated components such as phenolic compounds, alcohols, ketones and aldehydes. After a refining and upgrading process, it can be used at any level in the mixture with the associated petroleum fuel, which is a characteristic of a drop-in biofuel (DBF). Without upgrading, bio-oil is utilizable in stationery engines for heat/power generation. The technology of bio-oil production is discussed in Chapter 5.

2.2.5 Biohydrocarbons

This hydrocarbon, similar to the components of fossil fuels, is produced from biological materials, such as vegetable oils, fats or fatty acids. Unlike other biofuels, biohydrocarbons can be used directly as a DBF to substitute for gasoline, diesel, or jet fuel, which are also hydrocarbons. The production technologies of biohydrocarbon fuels are discussed in Chapter 5.

2.3 History and projection of liquid fuel supply and demand in Indonesia

2.3.1 Historical production, use, export, and import

Indonesia's crude oil production is declining while the consumption for oil refinery input is increasing. Hence, crude oil exports are decreasing, while imports are going up. In 2017, crude oil production was around 300 million barrels (MMbbl), of which around 100 MMbbl were exported, with an additional 150 MMbbl imported. The import of refined petroleum products reached around 370 MMbbl (Fig. 2.1).

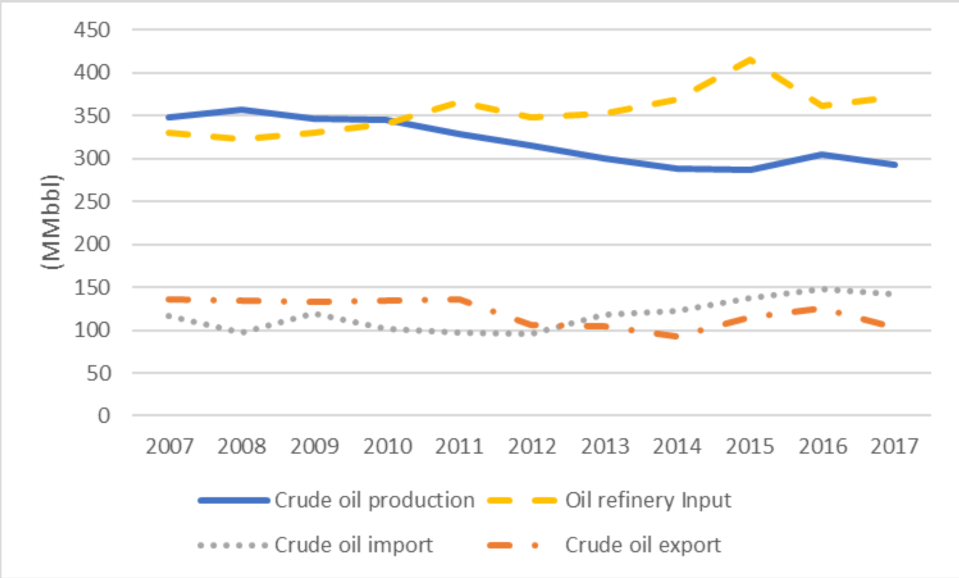


Fig. 2.1 Crude oil production, exports and imports, and the consumption by oil refineries by Indonesia between 2007-2017 (MEMR, 2018)

Crude oil products consist of fuels and non-fuels. Indonesia has been a net-importer of oil products since 1997, and of crude oil plus oil products since 2004 (Fig. 2.2).

Import of crude oil products increased from around 25 Gl (160 MMbbl) in 2007 to around 30 Gl (190 MMbbl) in 2017 (Fig. 2.3). The import volume has been dominated by gasoline which long-term trend is increasing.

Existing biofuels at commercial scale in Indonesia consist of biodiesel and bioethanol. In 2017, the oil refinery capacity was 1.2 MMbbl per day or around 70 Gl/yr, while the biofuel industry capacity was 12 Gl/yr biodiesel and 40 Ml/yr bioethanol (MEMR, 2018). For economic feasibility, the only productive biofuel has been biodiesel from palm oil, although demand for gasoline imports has been much higher than for diesel fuels (Fig. 2.3). Cassava and molasses feedstocks for ethanol production are more economically viable for non-energy uses.

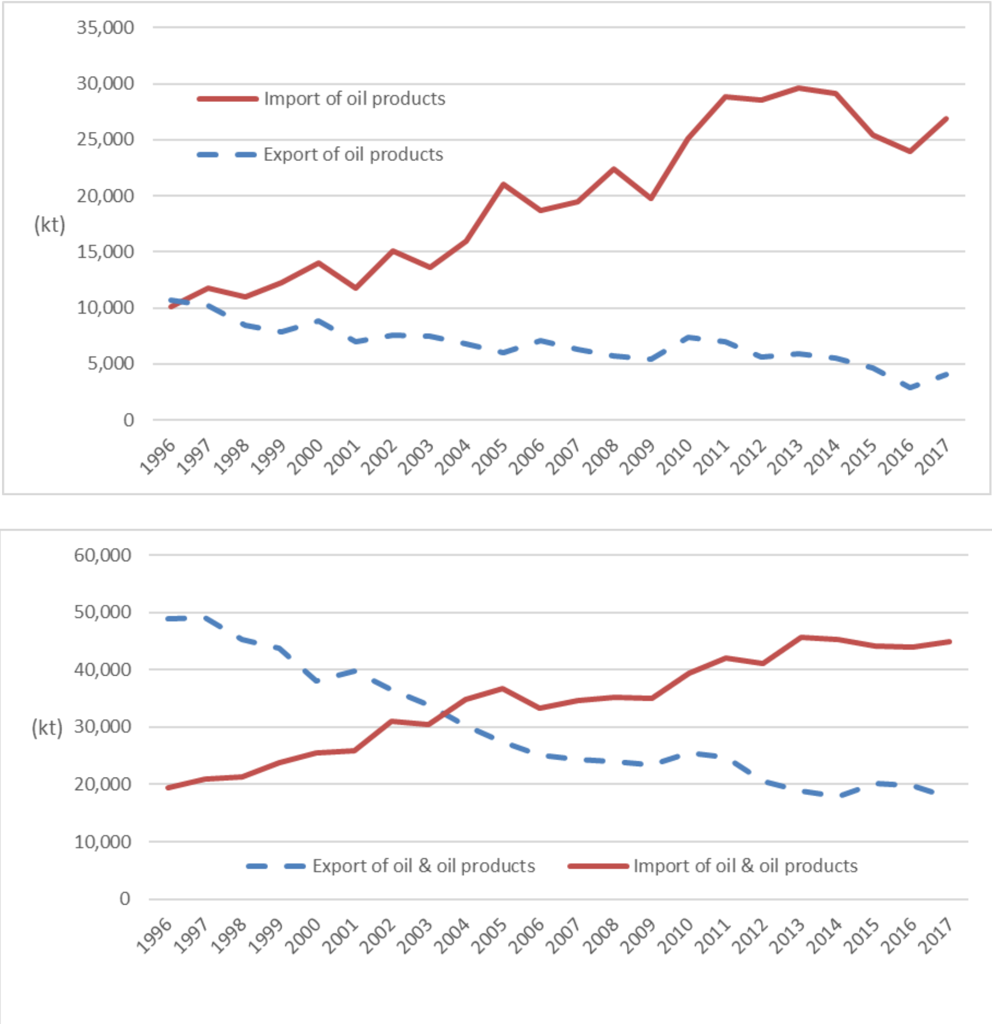


Fig. 2.2 Export and import of oil products (top) and crude oil plus oil products (bottom) by Indonesia between 1996-2017 (BPS, 2018a)

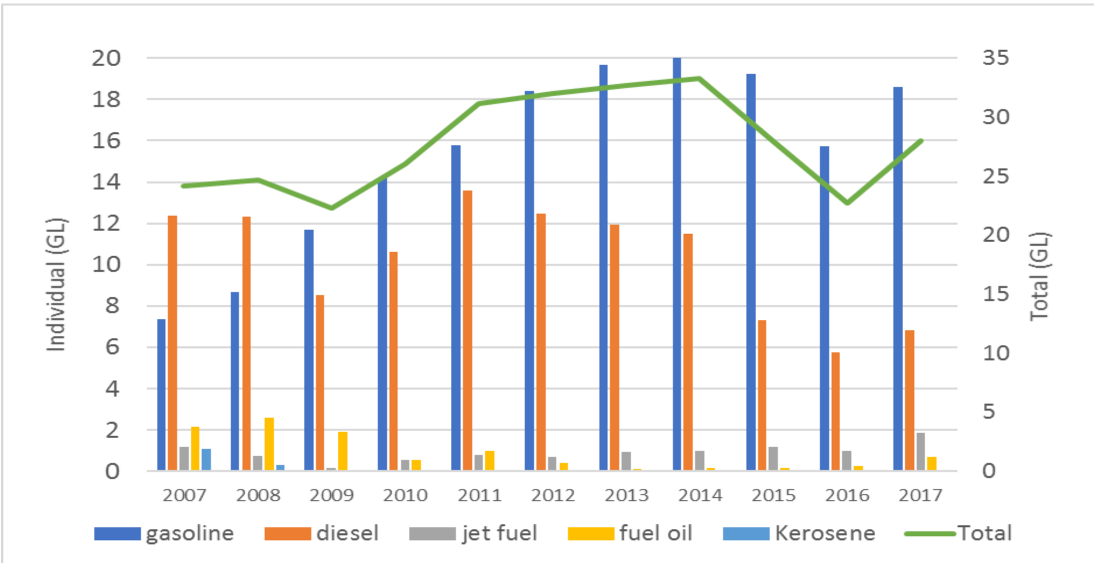


Fig. 2.3 Import of refined petroleum products for Indonesia between 2007-2017 (MEMR, 2018)

Biodiesel has been produced since 2009, following up the Minister of Energy and Mineral Resources (MEMR) Regulation Number 32/2008 which regulates the minimum level of biofuels use. In 2017, the installed capacity for biodiesel was 11.6 Mt or around 13 Gl, and the production rate was 3.42 Gl increased from 0.19 Gl in 2009 (Fig. 2.4). The consumption in 2017 was 2.57 Gl, increased from 0.12 Gl in 2007. The surplus biodiesel produced was exported. Biodiesel production and consumption fluctuations were affected by the economic situation (Section 2.4.2).

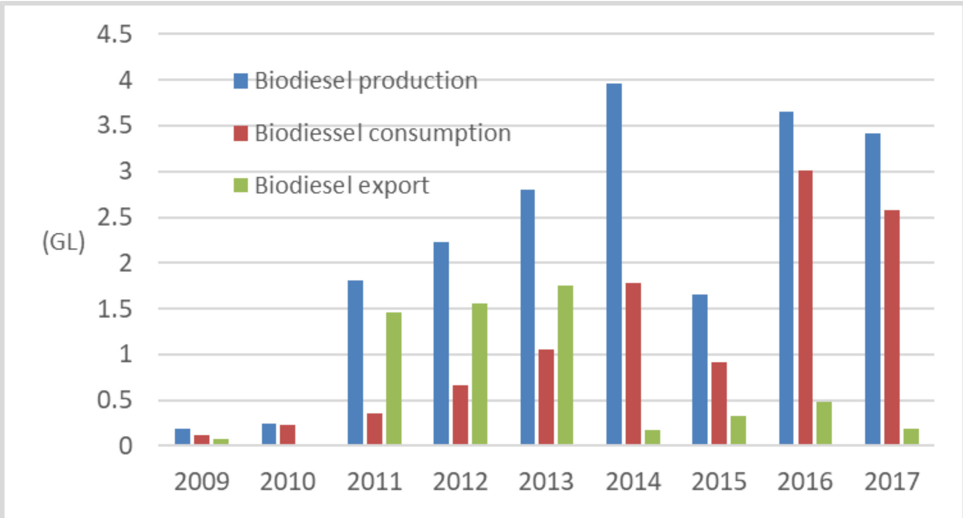


Fig. 2.4 Biodiesel supply and demand for Indonesia between 2007-2017 (MEMR, 2018)

CPO is currently the only feedstock used for biodiesel production. Indonesia is the world's largest CPO producer with around 38 Mt produced in 2017 (Fig. 2.5). Despite this large production, domestic consumption is around 20-25% of the total, so that most is exported.

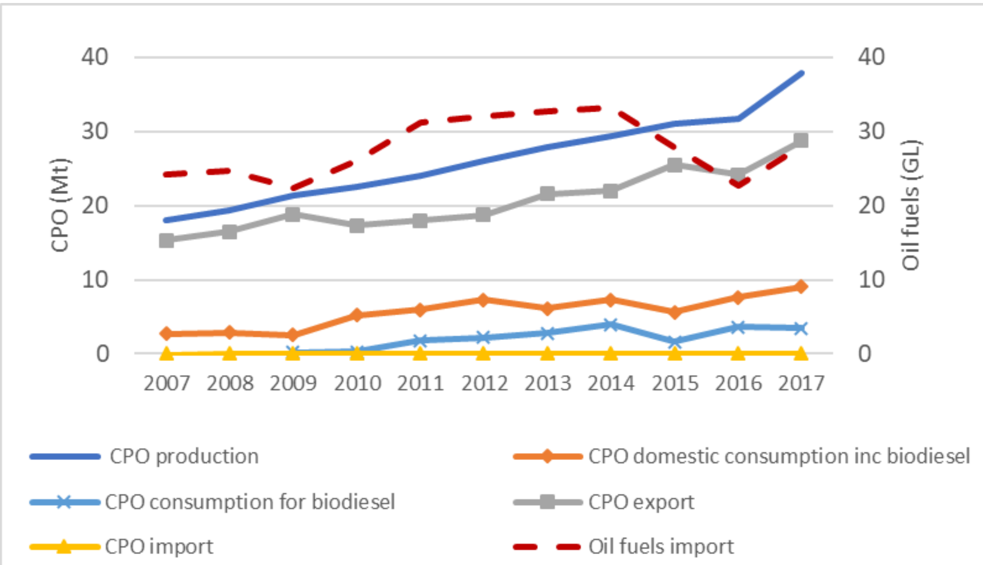


Fig. 2.5 Production, consumption and import of CPO, and export and import of petroleum fuels by Indonesia between 2007-2017 (MOA (2016), BPS (2017); MEMR (2018); GAPKI (2018))

2.3.2 Projection of future production, use, export, and import

World petroleum and liquid fuels use are projected to increase by 38% from 87 MMbbl/d (around 32 billion barrel in 2010) to 119 MMbbl/d (43 billion barrel in 2040). The growth outlook of liquid fuels use will be mostly driven by demand in developing countries, especially in Asia and the Middle East, at an 85% share (EIA, 2014).

Indonesia's liquid petroleum fuel demand is projected to increase from around 75 Gl in 2018 to around 260 Gl in 2045, while the oil fuels production is projected to increase at a much lower rate, from around 50 Gl in 2018 to around 135 Gl in 2045 (Fig. 2.6). This means the crude oil deficit by 2045 will reach 125 Gl and this will need to be filled by crude oil imports or alternative substitutes such as liquid biofuels (Section 2.5.2).

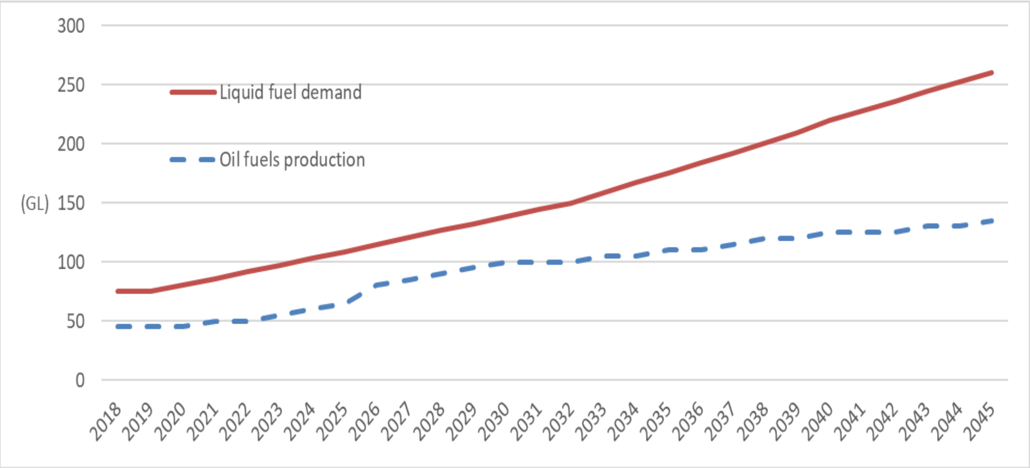


Fig. 2.6 Projection of liquid fuel demand and oil fuels production by Indonesia by 2045 (BPPT, 2018)

The crude oil production is projected to go down from around 300 MMbbl (48 Gl/yr) in 2018 to slightly below 100 MMbbl (15 Gl/yr) in 2045. Therefore, to supply crude oil for the oil refinery input, the crude oil import is projected to increase from around 180 MMbbl (28 Gl) in 2018 to around 950 MMbbl (151 Gl) in 2045 (Fig. 2.7).

Thus, the total import demand by 2045 is projected to reach around 125 Gl petroleum fuels and 151 Gl crude oil, less any biofuel or other substitutes implemented.

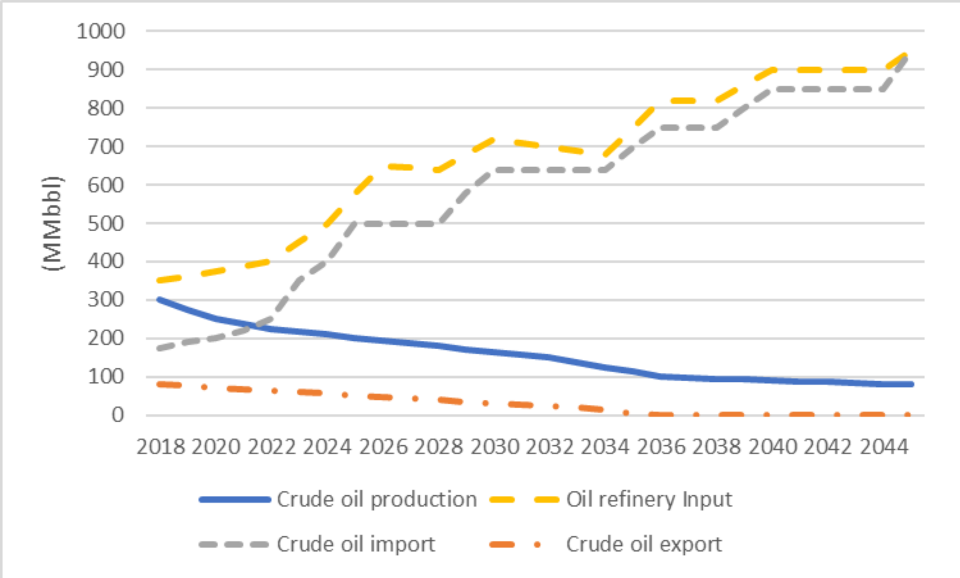


Fig. 2.7 Projection of crude oil supply and demand for Indonesia by 2045 (BPPT, 2018)

CPO is the main feedstock for biodiesel production which is also suitable for the production of drop-in biofuel (DBF) to substitute for petroleum fuels in Indonesia (Chapter 5). It is projected that in 2045 CPO production will reach 60 Mt (70 Gl), when crude oil imports will be around 135 Gl (Fig. 2.8). Assuming the rate of CPO use for non-biofuel keeps the same by 2045, the potentially remaining CPO can only meet around one-third of the crude oil import demand (Fig. 2.8).

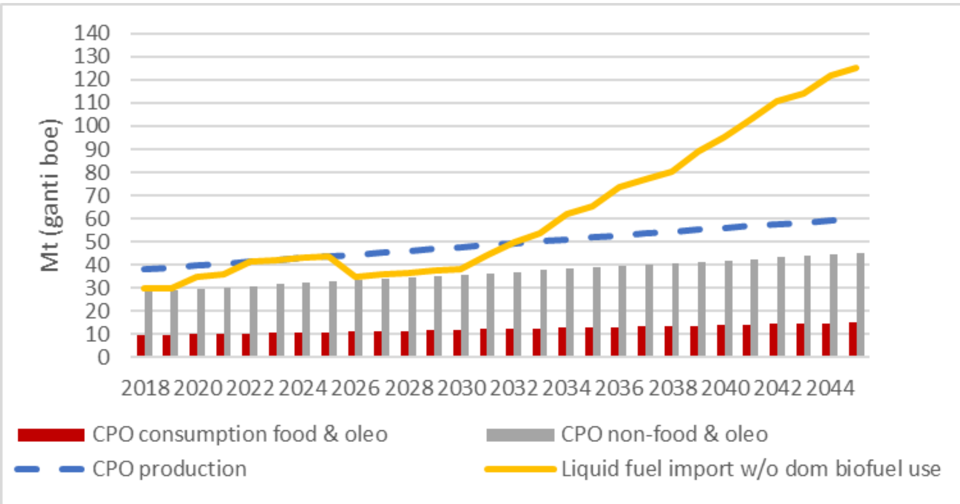


Fig. 2.8 Projection of liquid fuel import demand without biofuel use for Indonesia by 2045 (BPPT (2018), BPS (2017))

2.4 Interrelationship between the liquid biofuel development and the economy in Indonesia

2.4.1 Historical balance of trade

The dynamics of liquid biofuel development including the policy/measures (Section 2.4.1) and actions have been influenced by the dynamics of economic condition especially the current account deficit (CAD) or a deficit status of the national balance of trade. Balance of trade (BOT) is defined as "the difference between the money that a country receives from exports and the money it spends on imports" (CBED, 2018). The exports and imports consist of fossil oil & gas (oil & gas) and non-oil & gas components (Fig. 2.9).

Fig. 2.9 shows values of BOT and components between 1975 and 2017. The annual growth for BOT of non-oil & gas in the last two decades was 13.68% for exports and 21.87% for imports, while in last decade was 4.19% for exports and 3.45% for imports. It seems uneasy to change values of the non-oil & gas export as well as the import. When the non-oil & gas export increased sharply, so did the non-oil & gas import. It is because to produce export goods it requires import of several materials. Therefore, it is projected that the difference between non-oil & gas export and import will keep similar to the current trend.

In 2012, the BOT was in deficit for the first time since 1976, which was mainly impacted by the deficit in BOT of oil & gas especially oil products. The only former deficit happened in 1975 which was caused by BOT of non-oil & gas.

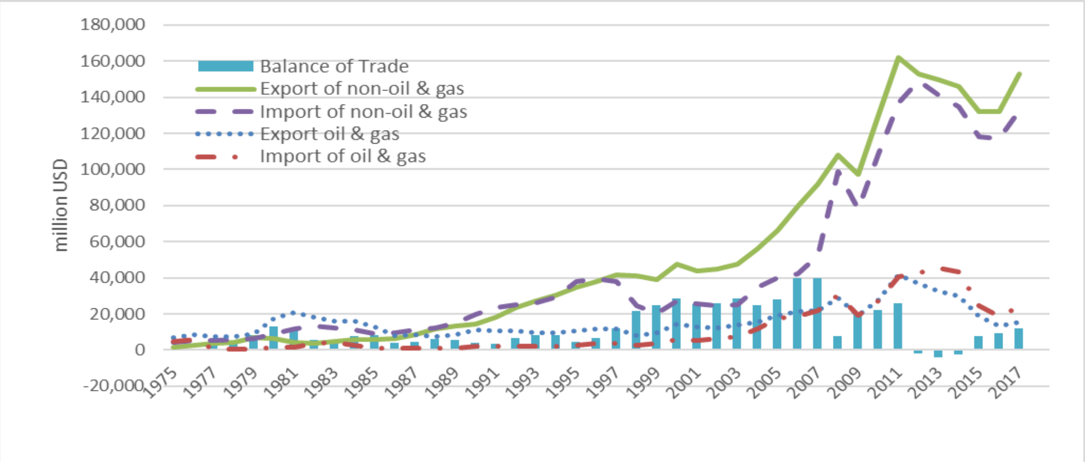


Fig. 2.9 National balance of trade for Indonesia between 1975-2017 (BPS, 2018a)

BOT is calculated by multiplying the volume balance with the price. Fig. 2.10 shows the export and import volumes of oil & gas and the balances, compared to oil & gas BOT and national BOT. The oil & gas export volume is decreasing while the import is increasing, has brought Indonesia to become a net-importer of oil & gas since 2004.

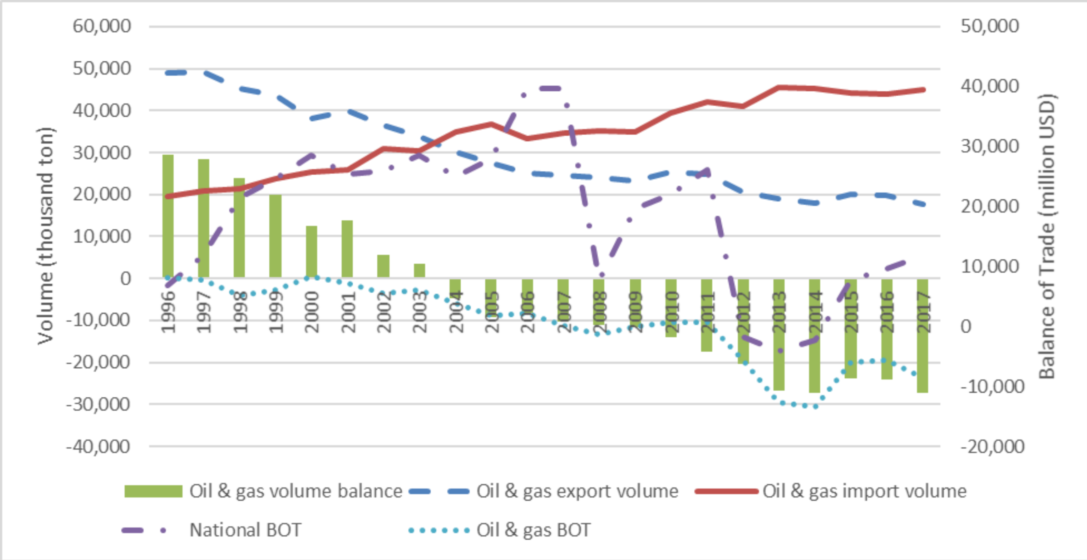


Fig. 2.10 Oil & gas balance for Indonesia between 1996 - 2017 (BPS (2018a); MEMR (2018))

Liquid biofuel production and utilization in Indonesia will reduce petroleum fuels imports and hence save foreign exchange expense and improve BOT of oil & gas and thus national BOT. However, biofuel development is challenged by a low oil price. When oil price was low, the liquid biofuels price was usually higher which increased oil fuels import and thus decreased BOT (Fig. 2.11).

The national BOT fluctuation pattern followed BOT of non-oil & gas due to BOT of non-oil & gas dominates the national BOT. However, the major trend of national BOT follows BOT of oil & gas due to BOT of oil & gas plays a larger role over time (Fig. 2.11).

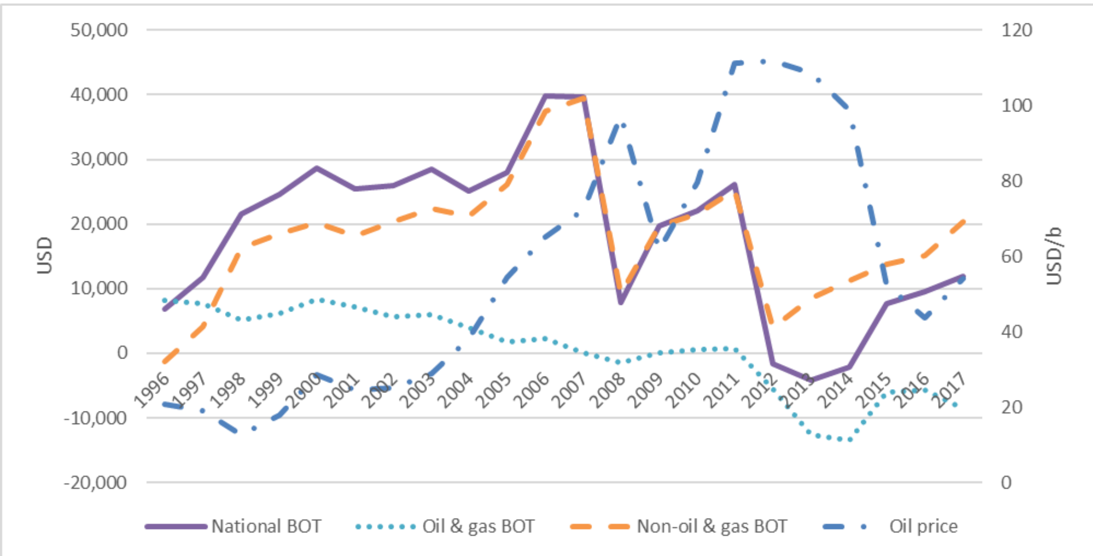


Fig. 2.11 Crude oil price between 1996 - 2017 (BPS (2018a), IndexMundi (2019a))

2.4.2 Balance of trade versus biofuel development

The policy and measures in liquid biofuel development in Indonesia have developed dynamically. The role of liquid biofuels in national energy security has been recognized by policymakers since 1990s. However, the efforts for the implementation was not significant unless pressure from BOT existed.

This study did a yearly-based observation from 2003 until 2018 using reports and news, which shows the dynamics of the economic condition and the actions taken for liquid biofuel development. The economic variables cover crude oil price, CPO price, oil & gas balance of volume (BOV), and national BOT. The actions were indicated by the progress in the policies and measures development, and the consumption of palm biodiesel as the only type of liquid biofuel which was available significantly in the market. The details of the observation are described in Table 2.1.

It is shown that significant actions were demonstrated only when the national BOT was a deficit that raised a sense of urgency for national liquid fuel sovereignty as expressed by the President. In showing the relationship of liquid biofuel development with the economic situation as driven by the sense of urgency by the President (SU), this study classified the SU level of existence into low and high.

The model in this study uses oil price projections by World Bank for 2018-2020 (WorldBank, 2018), and by IEA "Sustainable Development Scenario" for 2021-2040 that ranges from USD 57-72/bbl (IEA, 2017b) and extrapolated up to 2045. The oil price in 2018 was assessed without reflecting the market fundamentals. Therefore, the World Bank adjusted the oil price projection for 2018-2030 to USD 67-70/bbl (WorldBank, 2018). Projected BOT was calculated by multiplying BOV using time series from previous sections, with the crude oil price.

The dynamics of biofuel development show an interrelationship with the economic situation:

- In 2003 the international oil price hit a record at USD 29/bbl, but oil & gas BOT and national BOT stayed positive.
- In 2004 the oil price hit a new record at USD 38/bbl, an increase of USD 10/bbl over 2003. The Indonesian oil & gas balance of volume (BOV) was negative for the first time (that made Indonesia an oil net-importer country), while oil & gas BOT and national BOT kept positive. A sense of urgency was emerging.

Table 2.1 Assessment of level of sense of urgency by the President (SU) for liquid fuel sovereignty based on the dynamics of economic situation

Year	**Crude oil price averaged [a], (Brent, USD/bbl)**	**Crude palm oil price Jan-Dec [b] (USD/t)**	**BOV of oil & gas (exports-imports) [c] (kt)**	**BOT of national and oil & gas [c] (million USD)**	**Biodiesel use [d] (Gl)**	**Highlight**	**Assessment on SU**
2003	29	400-500	3,537	28,508 & 6,041	N/A	Last positive BOV	baseline
2004	38	400-500	(-4,634)	25,060 & 3,913	N/A	Urgency rose by deficit in oil & gas BOV	low
2005	55	400-500	(-9,233)	25,979 & 1,774	N/A	BOT of oil & gas and national stayed positive	low
2006	65	400-600	(-8,126)	39,733 & 2,247	N/A	BOT of oil & gas and national stayed positive	low
2007	72	600-950	(-10,182)	39,628 & 156	N/A	Oil & gas BOT was slightly above zero	low
2008	97	1050-500	(-11,181)	7,823 & (-1,427)	N/A	Oil & gas BOT went negative for the first time	high
2009	62	550-800	(-11,663)	19,681 & 38	0.12	Oil & gas BOT returned positive	low
2010	80	790-1250	(-13,918)	22,116 & 627	0.22	BOT increased	low
2011	111	1250-1050	(-17,343)	26,061 & 776	0.36	BOT increased	low
2012	112	1181-776	(-20,482)	(-1,669) & (-5,587)	0.67	Deficit in oil & gas BOT was threefold of 2008	high
2013	109	800-900	(-26,696)	(-4,077) & (-12,633)	1.03	Biofuel mandatory was accelerated	high
2014	99	700-800	(-27,323)	(-2,199) & (-13,441)	1.78	Preparation of funding from palm oil export fee to support biodiesel pricing	high
2015	52	500-600	(-23,952)	7,672 & (-6,039)	0.92	National BOT stayed positive	low
2016	44	500-700	(-24,067)	9,533 & (-5,634)	3.01	Significant biodiesel efforts to strengthen palm oil market which had weakened for last several years.	high
2017	54	700-600	(-27,252)	11,843 & (-8,572)	2.57	National BOT increased	low
2018	55-80	650-500	no data	(-8,496) & (-12,464)	no data	BOT was the worst ever; Additional pressure from weakening palm oil market	high

[a] IndexMundi (2019b); [b] IndexMundi (2019a); [c] BPS (2018a); MOT (2019) [d]

- In 2005 oil & gas BOT and national BOT were significantly lower than the previous year but remained positive. The sense of urgency was assessed as low and kept as it existed.
- In 2006 both oil & gas BOT and national BOT got higher. The Presidential Instruction Number 5/2006 concerning provision and utilization of biofuel as other fuel was enacted. The sense of urgency was assessed as low and moved efforts to improve BOT.
- In 2007 national BOT was slightly lower than the previous year, while oil & gas BOT decreased to slightly above zero, which was a critical point. Law No. 30/2007 on Energy was enacted, although The Presidential Instruction 5/2006 had not been implemented. Urgency was assessed as low.
- In 2008 the oil price peaked at USD 97/bbl, and oil & gas BOT was negative for the first time. MEMR Regulation 32/2008 concerning provision, utilization, and business of biofuels as an alternative fuel was established to accelerate biofuel provision and utilization. Urgency was assessed as high.
- In 2009 oil & gas BOT increased to slightly above zero as the oil price decreased to USD 62/bbl. MEMR Regulation 32/2008 started the implementation but at a far lower level than the mandatory. Urgency was assessed as low.
- Biodiesel was used for the first time, sold as a blend at pump stations of PT.Pertamina (a state-owned energy company) when marketed as a blend.
- In 2010 biodiesel use doubled yet was still far lower than the regulation as mandated in MEMR Regulation 32/2008. Oil price increased to USD 80/bbl. The oil & gas BOT slightly increased. Urgency was assessed as low.
- In 2011 biodiesel use doubled yet was still far lower than the regulation mandatory. The oil price rocketed to USD 111/bbl. The oil & gas BOT slightly increased. Urgency was assessed as low.
- In 2012 the oil price reached a new peak at USD 112/bbl, and the oil & gas BOT was in deficit for the second time but at more than threefold of 2008. The national BOT was negative for the first time since 1976, at USD -1,669. The biofuel use was almost doubled from 359 Ml in 2011 to 669 Ml. Urgency was assessed as high.
- In 2013 national BOT was negative and doubled than the previous year, hit a new record at USD (-4,077). Oil price kept high at above USD 100/bbl. The President

instructed the coordinating ministers for accelerating biofuel implementation. MEMR Regulation 25/2013 was enacted to accelerate the increase level and area of biofuel use to support macroeconomy policy and reducing oil fuels import. The target of biodiesel use in transportation by 2025 was increased from 20% to 25%, even though the previous mandate of 2008 had not yet well implemented. Biodiesel use increased to slightly above 1 Gl. The urgency was assessed as high.

- In 2014 national BOT was better than in 2013 but still negative. Oil price slightly decreased. Biodiesel use increased significantly to 1.8 Gl. The Agency for Collection and Use of Oil Palm Plantation Fund (BPDPKS) was in preparation to collect an export fee from palm oil that can be used for supporting sustainable oil palm such as replanting, R&D, promotion, infrastructure, and downstream industry, and to pay for any price difference between biodiesel and diesel fuel. To promote biofuel use, Government Regulation 79/2014 on National Energy Policy was enacted. A guide for incentive provision from oil palm plantations was provided in Law 39 2014. Road testing of vehicles using B20 over 40,000 km (diesel motor endurance) was accomplished, after being initiated in 2012. The urgency was assessed as high.
- In 2015 the oil price plummeted to USD 52/bbl, and the national BOT was back to positive, while oil & gas kept negative at USD (-6,039) billion. Biodiesel use halved to 915 Ml and the CPO price went down due to decreasing demand for exports. The 2008 target was revised higher to absorb more palm-biodiesel. BPDPKS was established and have become the provider of biodiesel subsidy since August 2015, replacing the state budget in the previous implementation. Efforts were driven by the weakened CPO export market. MEMR Regulation 12/2015, the second amendment on MEMR Regulation 32/2008 was enacted to support macroeconomy policy, reducing oil fuels import, and saving foreign exchange through accelerating increase level and area of biofuel use. Besides, some instruments were enacted to elaborate incentives provision by the palm oil industry, namely Government Regulation 24/2015, Presidential Regulation 61/2015, Minister of Finance Regulation 113/2015, and Minister of Trade Regulation 54/2015. The target of transport biodiesel use by 2025 was increased from 25% to 30% of blend, even though the previous mandate had not yet well implemented. The urgency was assessed as low.

- In 2016 the oil price decreased, and the national BOT increased. The biodiesel use was high and hit a new record at 3.0 Gl. Biofuel efforts were driven by weakened CPO export market. MEMR Regulation 26/2016 on using incentives from the palm oil industry in biodiesel utilization, was established. The fund collected by BPDPKS started the full implementation. The urgency was assessed as high.
- In 2017 the oil price stayed low at USD 54/bbl, and the national BOT kept positive. CPO price increased, and biodiesel use decreased by around 15% to 2.6 Gl. Efforts were driven by weakening CPO export market. Presidential Regulation 22/2017 concerning General Planning for National Energy (RUEN) was enacted, which set actions for supplying 11.6 Gl biodiesel and 3.4 Gl bioethanol (lower than the mandatory in MEMR Regulation 12/2015). The urgency was assessed as low.
- In 2018 oil price increased and the national BOT started to be in deficit in January, and the monthly BOT hit five-years record in July 2018. The national BOT by September was around USD (-15,000) million, while the full year BOT was around USD (-8,500) million which was the worst BOT ever. The BOT of oil and gas hit a new record at around USD (-12,500) million.

As the main cause of the deficit was the oil & gas BOT, the situation drove extraordinary efforts to maximize biofuel utilization, including any opportunities for implementing drop-in biofuels. At the same time, the CPO export market weakened so that the domestic use through biodiesel implementation was pushed. Additional pressure also came from the approaching deadline for the target of 23% renewable energy in 2025, where liquid biofuel was considered one of the easiest solutions.

All efforts were maximized but restricted due to biodiesel availability caused by transport limitations over the archipelago and the limitation for increasing the mandated blend concentration due to engine technology constraints.

The President urged for implementation of 100% biofuel using palm oil feedstock on 4th August 2018 (Nugroho, 2018) and technologies for producing DBF production was seriously discussed at the national level. On 1st September 2018, biodiesel blends of 20% with diesel (B20) were implemented in all sectors.

Three regulations were enacted in 2018:

(i) Presidential Regulation 66 aimed to amend Presidential Regulation 61/2015 concerning collection and use of oil palm estate fund;

(ii) MEMR Regulation 41 concerning the provision and utilization of biodiesel in the financing framework of the Indonesian oil palm estate fund, and

(iii) MEMR Regulation 1770/2018 on 2nd amendment of MEMR Regulation 6034/2016 on the market price index of biofuel mixed with fossil fuels.

Besides the regulations mentioned, several lower-level measures were also established to support technical issues such as defining biodiesel specifications.

The technology for DBF production developed at Institut Teknologi Bandung (ITB) (Chapter 5), a tertiary education institution in Indonesia, was discussed in many places and the R&D facilities visited by relevant ministers. In November, the stakeholders produced palm oil-based DBF using ITB technology through co-processing a 12 Ml/batch in three oil refinery units of Pertamina, the national oil company. The co-processing 5-10% palm oil was successfully accomplished (DGNREEC, 2018). Bio-jetfuel use in aviation engines was also prepared. Urgency was assessed as extremely high.

The assessment on the sense of urgency level for liquid fuel sovereignty by The President and the economic conditions were shown in Table 2.1. Overall, the urgency was drastically up and down. The danger of current account deficit (CAD) was not being awared of until it became a reality. Unless the current account went into deficit, it was not believed that the system had a problem. The oil & gas BOV and BOT tended to get worse after each became negative for the first time. It means, without adequate efforts, the national BOT would be becoming negative not long after the negative oil & gas BOV and BOT.

The sense of urgency by the President in making and implementing decisions determined biofuel implementation. Unfortunately, the sense of urgency was only an action responding the negative balance of trade and the low CPO price. Fig. 2.12 shows the feedback loop between national BOT and biofuel use.

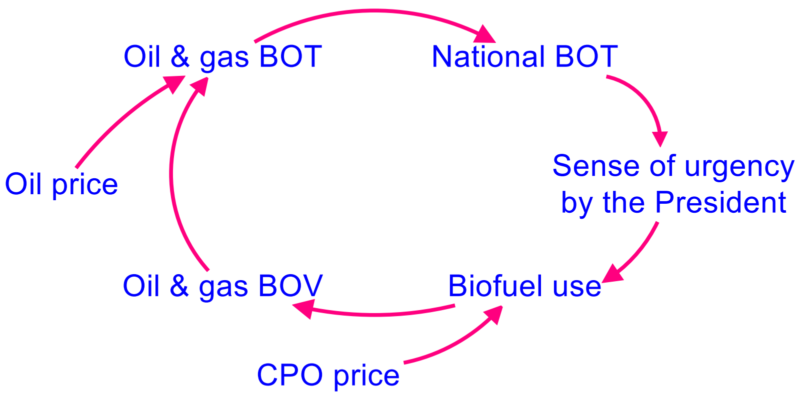


Fig. 2.12 A feedback loop of the sense of urgency and the biofuel use through BOT without a future vision

Indonesian economic growth by 2018 had continued strongly so that more imports of capital goods and intermediary goods (inputs in producing other goods) were resulted. Consequently the current account deficit (CAD) fell further (Sebayang & Natalia, 2018). As the Indonesian economic growth is projected relatively high up to long-term, the non-oil & gas BOT is estimated to change hardly. Considering the projection of oil fuel demand (Section 2.3.2) and the oil price projection by IEA and World Bank (IEA (2017b); WorldBank (2018)), the oil & gas BOT is likely to stay deficit in the long term. Thus, the national BOT seems to be in deficit in most of the upcoming years, in the condition of a similar level of biofuel use.

The national BOT being in deficit will drive high urgency which will increase biofuel use. To some extent this will, in turn, decrease the urgency that will decrease biofuel use, create BOT deficit, increase urgency, and so on. If the biofuel supply is never fully utilized to avoid CAD, the urgency will keep high which means the counter efforts will stay high to maximize utilization of DBF that uses feedstock from marginal land.

However, the oil price prediction accuracy could not be guaranteed. It is possible that if oil prices are low, national BOT will be positive so this puts no pressure on the urgency level. Therefore, an anticipative action is required to keep the urgency level high enough to encourage biofuel development and prevent the deficit balance from increasing in the future.

Anticipative actions can support investment in technology that should be allocated annually regardless of the oil price, with more allocation in easier times. For example, when crude oil and CPO prices enable the biodiesel price to be lower than diesel fuel, more funds can be allocated by BPDPKS for investing in technologies for drop-in biofuel production. Fig. 2.13 shows the loop where the urgency is responsive to national BOT as well as driven by a future vision to prevent the recurrence of negative BOT.

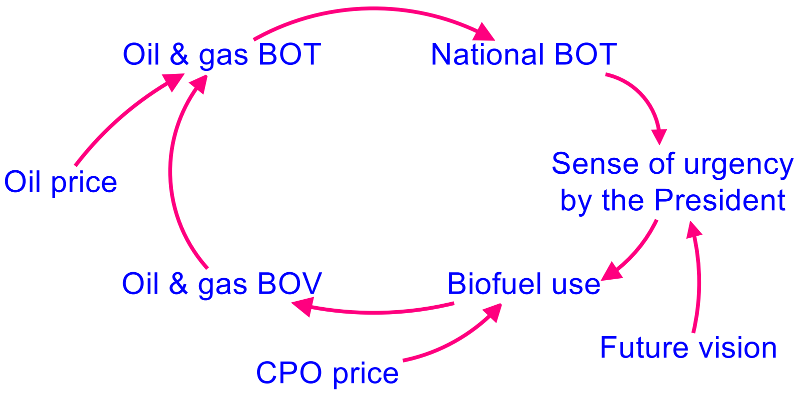


Fig. 2.13 A feedback loop of the sense of urgency and the biofuel use through BOT with a future vision

2.5 Impacts of liquid biofuel production and use in Indonesia

There has been increased global concern around sustainability issues in every development aspect including energy. Sustainability includes four criteria to be met, namely environmental, economic, social and political (MIT (2015); Sachs (1999) in Musango (2012)). Some development initiatives related to sustainability have been set at the global level, such as the Sustainable Development Goals (SDG).

The SDG 2030 agenda of the United Nations has 17 goals in which liquid biofuel development in Indonesia can directly contribute to five:

#7 clean energy;

#8 good jobs and economic growth;

#9 innovation and infrastructure;

#13 climate action; and

#17 partnerships for the goals.

In many cases, including bioenergy development in Indonesia, the political dimension plays a critical role. However, it is hard to find studies that discuss the political dimension in the sustainability context, especially in the energy sector. This study explicitly assesses the political aspect to better understand the systems and help with providing more effective solutions.

Political sustainability is defined as providing a satisfying overall framework for national and international governance (Sachs (1999) in Musango (2012)). An action in liquid biofuel is politically sustainable if it allows the fulfilment of current goals and resource needs without compromising future goals and needs (Broniatowski and Weigel (2004); WCED (1987)).

Priority indicators for bioenergy sustainability might be different for other countries, depending on their sustainability goals (Dale, Efroymson, Kline, & Davitt, 2015). Based on indicators and key issues of bioenergy sustainability that have been globally developed (RAE (2017); GBEP (2011); UN-Energy (2007)), this study emphasizes several impacts of liquid biofuel development in Indonesia that is simulated in the model (Chapter 7) and classified into socioeconomic, environmental, and political impacts.

2.5.1 Socioeconomic impacts

Liquid biofuel implementation is important in socioeconomic development to improve energy security and economic growth at both national and local scales. Nationally it will reduce Indonesian dependence on oil fuel import (Section 2.3) that in turn improves national energy security and the economy. Locally it supports rural development.

Production and use of liquid biofuel is crucial for Indonesian energy security. The liquid fuel demand by 2045 is projected to be around 260 Gl of which 130 Gl needs to be imported (BPPT, 2018) because Indonesian crude oil production is declining and estimated to drop to less than 6 Gl in 2045 from around 40 Gl in 2017 (BPPT, 2018).

Furthermore, liquid biofuel implementation is also very important for the Indonesian economy, by reducing petroleum fuels imports. Indonesia imported around 30 Gl of petroleum products or more than half of its liquid fuel demand and projected to increase together with all other energy types in line with its population and economic growth (MEMR (2018); BPPT (2018)).

Economically, liquid biofuel production and use will strengthen national economic growth through increasing the trade balance. As a major net oil importer, Indonesia’s trade balance is sensitive to the production and use of liquid biofuels. Trade balance indicates a country’s economy and can determine the public’s decision to hold any financial instruments based on that currency exchange rate (Section 2.4).

High petroleum fuel imports requires more foreign exchange to pay for the imports, which weakens the local currency that is used to buy foreign currency. This in turn leads to the requirement of more foreign exchange for paying for the fuel imports. Thus, the high oil fuel imports and the currency in Indonesia has been in a vicious cycle. That is why since becoming a net oil importer, Indonesia's currency has always dropped when the oil price increased. Also, a weaker currency risks forcing petroleum fuel price increases and inflation.

At the local level, liquid biofuel production will benefit rural development especially with regard to energy self-sufficiency and local economic growth by increasing gross regional domestic product (GRDP). In rural areas and small islands that have low GRDP and have no petroleum resources, such as Sumba island (Chapter 6), a new liquid biofuel industry could dramatically increase the economic growth.

Another economic impact of liquid biofuel implementation is supporting the bio-based economy covering production of food, industrial materials, and energy that utilize renewable resources. A bio-economy is considered by some to be the next era in economic development as it has been a vital option to the limitation of existing fossil resources and the realization of a zero-waste production process (EuropeanCommission, 2018).

2.5.2 Environmental impacts

Many development programmes are directed to boost decarbonisation of the economy, especially the energy sector which has contributed 72% of total global GHG emissions in 2013 (Friedrich, Ge, & Pickens, 2017). The World Bank stopped funding for coal exploration in 2010 and will stop it for oil and gas exploration after 2019 (Frangoul, 2017). In 2018, New Zealand became the first country that stopped off-shore oil and gas exploration.

"The Paris Climate Agreement" from the 21^{st} United Nations Framework Convention on Climate Change Conference of the Parties (UNFCCC COP 21) held between 30^{th} November to 12^{th} December 2015, has been ratified by 185 countries to date, including Indonesia (UNFCCC, 2019). The world is targeted to restrain the increase of atmospheric temperature by significantly below $2^{o}C$ in 2100 compared to the pre-industrial era (UN, 2015).

Total GHG emission reductions resulting from the voluntary pledges by countries prior to COP 21 are insufficient to stay below the global temperature target by 2030. Based on the pledges from the Intended Nationally Determined Contributions (INDCs) as submitted before 1 Oct 2015, the temperature decrease will be 2.5 – 2.7 ^{o}C which is higher than the maximum 2^{o}C international target (IRENA, 2015, p. 10). The projected 53-55 Gt CO_2e total emissions in 2030 after reductions due to the INDCs needs to be lowered by 15-17 Gt CO_2e if the world is to stay below the 2^{o}C target (IRENA (2015); CAT (2017)).

To limit global temperature rise to under 2^{o}C, the utilization of low-carbon energy resources must be accelerated (UN (2015); IRENA (2015)). Renewable energy uptake will need to double together with substantial energy efficiency improvements (IRENA, 2014). One of the most challenging efforts is decarbonisation of the transport sector.

Biofuels are the only non-fossil energy source available as a liquid that can be implemented in decarbonising the transport sector, so they are crucial in realizing the Paris Agreement. The high demand for liquid fuels for all types of transportation modes will continue to exist in the long-term. Vehicles for aviation, shipping and heavy-duty vehicles are expected to keep using liquid fuel in all countries (RAE (2017); Oberman et al. (2012)).

The INDCs has been was followed up through the Nationally Determined Contributions (NDCs) that were submitted by the parties/countries including Indonesia. The President of Indonesia stated at COP 21 that Indonesia would commit to reducing its greenhouse gas emissions from the business-as-usual scenario of 2,869 Gt CO_2e in 2030 by 29% through self-efforts or 41% involving foreign financial assistance (Indonesia, 2016). The 29% of emissions reduction which is equal to 834 Mt CO_2e includes 314 Mt from the energy sector and 497 Mt from the forestry sector. Liquid biofuels have a high potential to contribute to the Indonesian NDC, as it is used in almost the whole of the transport sector, which the consumption is projected to reach 260 Gl in 2045 (BPPT, 2018).

Biomass resources could also play a crucial role in the transition to cost-competitive renewable energy generation for use by battery electric vehicles (BEV) (McDowall, 2012). In the mid-term, the main energy technologies could include bio-derived liquid reforming and biomass gasification, while in the longer term, they could include hydrogen from water electrolysis using renewable energy sources and photo-electrochemical processes.

Light-duty vehicles (LDVs) in developed countries are predicted to become more electric as a greener option if using renewable electricity. For instance, to realize the Paris Climate Agreement, BEVs in Europe are targeted to account for all new vehicle sales that include 85% of LDVs by 2060 (IEA, 2017a). In Asia, Japan planned to increase its share of BEVs (McDowall, 2012).

2.5.3 Political impacts

Development of drop-in biofuel technologies involve both economic and environmental concerns of various parties toward sustainable development. Therefore, it can improve bipartisanship to support political sustainability which drives the investment (Green, 2016). Investment by the federal government is necessary to realize the development of the bioeconomy that is sustainable both politically and economically (Green, 2016).

This study assessed the political element often lacking in other studies on bioenergy sustainability.

The domination of BOT for the sense of urgency has obstructed biofuel development sustainability in Indonesia. Anticipative actions are needed to counter the current account deficit (CAD) and to prevent recurrence (Section 2.4.2). The anticipative actions include a continued allocation for investment on DBF technology innovation (Chapter 5) and setting the target for biofuel share according to existing capability.

It is common that a technology innovation policy involves cross-sectoral interests leading to potential for disharmony between the economists and the scientists or engineers. As reported from studies on Indonesian cases, the President was a crucial factor (Amir, 2008). This implied that in such cases the head of government should show the dominance in decision making. It means, the sense of urgency in technology innovation for liquid biofuel development should be understood by the President, who can instruct the start of required actions based on the history (Table 2.1).

Sustainable development spans over the long term, which relates to a future vision. The condition of lacking anticipative actions could be overcome by activating a future vision to drive the sense of urgency by The Indonesian President. This could be driven by a future vision for Indonesia such as stated in the Preamble of The 1945

Constitution: “to become an independent, united, sovereign, just, and prosperous nation”. The previous two visions can only be reached if the sovereignty is well established. The sovereignty covers all aspects including energy for which one of the main problems faced is the high dependence on fossil liquid fuel importation.

The future vision has been translated into shorter-term visions:

- “The Indonesian Dream 2015-2085” *(Impian Indonesia 2015-2085)* was handwritten by The 7th President, Mr Joko Widodo in 2015 that mentioned a point “Indonesia to become an independent country” (MNDP (2017); Appendix I).
- “The Vision of Golden Indonesia 2045” *(“Indonesia Emas 2045”)* was established to mark the 100th Independence Day. This vision has four pillars that include Sustainable Economy Development and National Security and Governance. (MNDP, 2017).

2.6 Model inputs

The model developed in Chapter 7 will utilize inputs from this chapter, especially in BOT calculation, the initial value for sense of urgency by the President, and national liquid fuel supply and demand.

- Various inputs required for the BOT calculation between 2018 and 2045 were taken from various sources as applied to depict Figs. 2.6 - 2.8.
  - Export and import values of oil and gas commodities were taken from BPPT (2018). The parameters consist of volumes of oil imports, petroleum product imports, oil exports, petroleum product exports, gas imports, gas product imports, LPG exports, LPG imports, gas exports, and gas product exports.
  - Crude oil prices were taken from IEA (2017b) and WorldBank (2018):
    - 2018-2020 from WorldBank (2018);
    - 2021-2040 from IEA (2017b) Sustainable Development Scenario, and
    - 2041-2045 extrapolation of data from IEA (2017b).
  - Oil products prices were using the “EIA formulae” (EIA, 2018):
    - Oil fuels average price is estimated 200% crude oil price.
    - LPG average price is estimated equal to crude oil price.

- Non-oil and gas export value and non-oil and gas import value were taken by extrapolating data from BPS (2018a), with assumption each growth of 5% (Section 2.4).
- CPO price from IndexMundi (2019b).

- Initial Value for the Sense of urgency by The President = 1 (Section 2.4.2).
- National liquid fuel demand and oil fuels production (Fig. 2.6).
- National crude oil supply and demand (Fig. 2.7).

2.7 Conclusions

- Existing liquid biofuels have an oxygenated molecular structure that limits use in blends with petroleum fuels. To enhance biofuel use, it is necessary to implement drop-in biofuels (DBF) that can be used at more flexible blend concentrations due to having similar characteristics to petroleum fuels. Liquid biofuels can be used extensively in existing vehicle engines and play an important role in the transition to battery electric vehicles (BEV).

- Up to 2045, Indonesia's demand for imported petroleum fuels and crude oil is likely to increase, whereas liquid biofuels are expected to be the most appropriate solution to reduce oil fuel imports up to 2045. Palm-based biodiesel is currently the only type of biofuel implemented in Indonesia but will likely be insufficient to meet liquid fuel demand by 2045. To further increase biofuel supply, the technology for DBF production and the use of feedstocks from other sources should be utilized as soon as possible, including from energy crops produced on marginal land, lignocellulosic biomass, and micro-algae.

- There is an interrelationship between liquid biofuel development and the economy in Indonesia. Currently the main drivers of biofuel utilization are the deficit balance of trade (BOT) and the low CPO price that enables biodiesel to be cheaper than fossil diesel. Biofuel development will in turn affect the BOT. The deficit BOT was predictable because the demand for liquid fuels is clearly increasing while the oil reserves are declining. However, anticipative actions were lacking. The government took a serious action only when the deficit was realized, when biofuel acceleration was limited by existing plant capacity and the distribution system due to the geographical conditions. This study recommends that biofuel development should be not only responsive to the deficit BOT but also anticipative to prevent the recurrence of deficit BOT, through sustained biofuel development actions.

- Liquid biofuel implementation has impacts on sustainability for which indicators have been developed globally. Sustainability indicators should be prioritized in accordance with a country's sustainability goals. The indicators that are most relevant to Indonesia's situation and biofuel production cover energy security, trade and foreign exchange balances, CO_2 emissions, and the sense of urgency.
- The sense of urgency in liquid fuel sovereignty through liquid biofuel implementation is required from multi-sectors. Therefore, it should be realized by the President that all supporting measures are implementable properly and timely.

CHAPTER 3
DEVELOPING A SIMULATION FRAMEWORK

3.1 Introduction

This chapter aims to conceptualize a simulation framework for bioenergy strategy in Indonesia through the utilization of marginal land and an appropriate liquid biofuel production technology.

A rationale for using a systems approach for assessing the proposed integrated strategy is provided in Section 3.2. Then, Section 3.3 provides a review of assessments of a liquid biofuel development strategy that takes account of feedstock and the conversion technology, considering the analysis results of priority sustainability indicators and the role of the liquid biofuel in Chapter 2. Finally, a framework for modelling the strategy assessment is proposed in Section 3.4.

The framework developed in this chapter is used to develop the computer model in Chapter 7. In building the model, the assessments from Chapter 4, Chapter 5, and Chapter 6 subsequently inform regarding the preferable plantation of marginal land, the suitable production technology for liquid biofuel, and the case study island.

3.2 The rationale of a systems approach for assessing integrated marginal land-based feedstock and appropriate future technology

3.2.1 The need for an integrated approach

A system is defined as "a collection of parts that interact with one another to function as a whole" (Maani & Cavana, 2007, p. 7).

The proposed strategy consists of four interrelated elements (Fig. 3.1): (i) preparation of feedstock from marginal land; (ii) preparation of a more appropriate technology for liquid biofuel production; (iii) liquid biofuel supply, and (iv) liquid fuel import demand, those determine the liquid fuel self-sufficiency.

Thus, in assessing the integrated strategy, it is necessary to develop an appropriate framework that can provide an understanding of the intrinsic relationships between the variables, such as enabled by a systems approach.

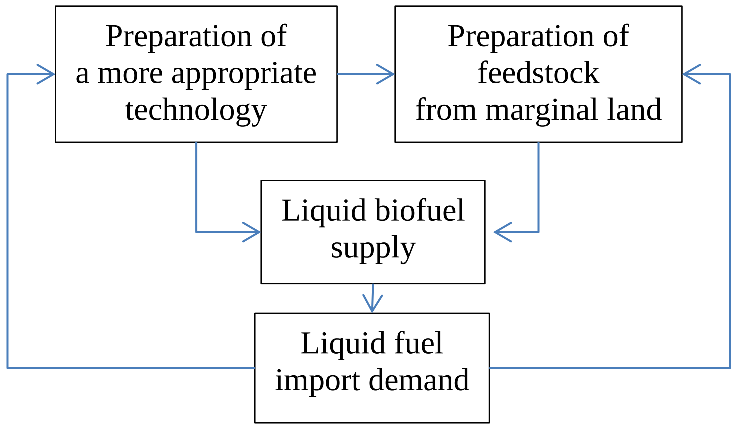


Fig. 3.1 Interrelationships between elements in the proposed strategy

Preparation of feedstock from marginal land normally takes several years because (i) marginal land use is commonly a multi-sectoral and multi-regional strategy in which the government makes decisions and coordinates; and (ii) it takes several years more to grow the plantation until harvesting the energy crops in forms of wood fuel and oilseeds (Chapter 4).

As the preparation of marginal land-based feedstock, the preparation of a more appropriate conversion technology for maximizing liquid biofuel utilization using local capabilities is also time-consuming. When assessed at local scope where a feedstock alternative is unavailable, feedstock from marginal land should be available when the conversion technology is ready for commercial production. Therefore, it is crucial to minimize delay in starting crop planting.

Thus, the assessment for implementing marginal land-based feedstock and appropriate future technology for bioenergy production should be conducted in an integrated way.

3.2.2 The modelling approach needed

The complex characteristics of the assessed system due to the existence of feedback loops makes it important to apply a computer model to aid with the challenge in understanding the nature and the important interrelationships of systems (Maani and Cavana (2007); Sterman (2000)). The integration of marginal land-based feedstock and conversion technology is a novel idea in bioenergy and liquid fuel strategy, so too is the use of a modelling approach for assessing the integrated strategy. Thus, to confirm the appropriateness of the framework, computer modelling is required.

The kind of approach that has been recognized for its capability in assessing feedback loops and covers multidisciplinary contexts is a systems approach, that can perform a qualitative assessment through a systems thinking model, and a quantitative assessment through a system dynamics model based on the systems thinking paradigm. The systems thinking model is visualized in a causal loop diagram, while a systems dynamics model is shown as a stock and flow diagram (Fig. 3.2).

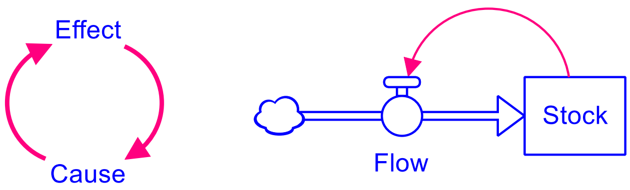


Fig. 3.2 Causal loop diagram (left) and stock and flow diagram (right)

Systems thinking is “a scientific field of knowledge for understanding change and complexity through the study of dynamic cause and effect over time” (Maani and Cavana (2007, p. 7). Systems thinking has several main principles, namely: (i) The big picture, (ii) short and long term, (iii) soft indicators, (iv) system as a cause, (v) time and space, (vi) system vs symptom, and (vii) ‘and’ vs ‘or’ (Anderson and Johnson, (1997, pp. 18-20) in Maani and Cavana (2007, pp. 8-11)). In addition, Senge (1990) stated “leverage point” as an important principle in systems thinking.

In solving a problem using a systems thinking approach, it is crucial to see the whole system that generates the symptom, rather than the symptom itself because the real problem exists in the structure and its dynamic behaviour. When a modification of the system is required, it is important to consider the changes that can promote as well as that balance any dynamic patterns. The pattern can be different in short versus the long term; therefore structure modification is adjusted based on the desired impacts in specific time ranges (Mella, 2017).

System dynamics was founded in the 1950s by Jay Forrester, a professor of Massachusetts Institute of Technology. It started when he helped a big corporate’s leaders with overcoming managerial problem using a system dynamics approach, bringing out his engineering and science background. Since then, system dynamics has developed and become an independent discipline and applied as a modelling approach in research subjects that require a quantitative assessment of a modelled system that has feedback loops. The subjects include organizational management, medical, education, politics, environment, and transdisciplinary subjects such as those found in sustainability issues. System dynamics has been recognized as an effective approach to manage such dynamic and complex problems (Sterman, 2000).

The use of a modelling approach will help with understanding interconnections, identifying significant variables or loops, trade-offs between sectors, and short versus long term impacts in the system. These all will help with improving current real-world systems.

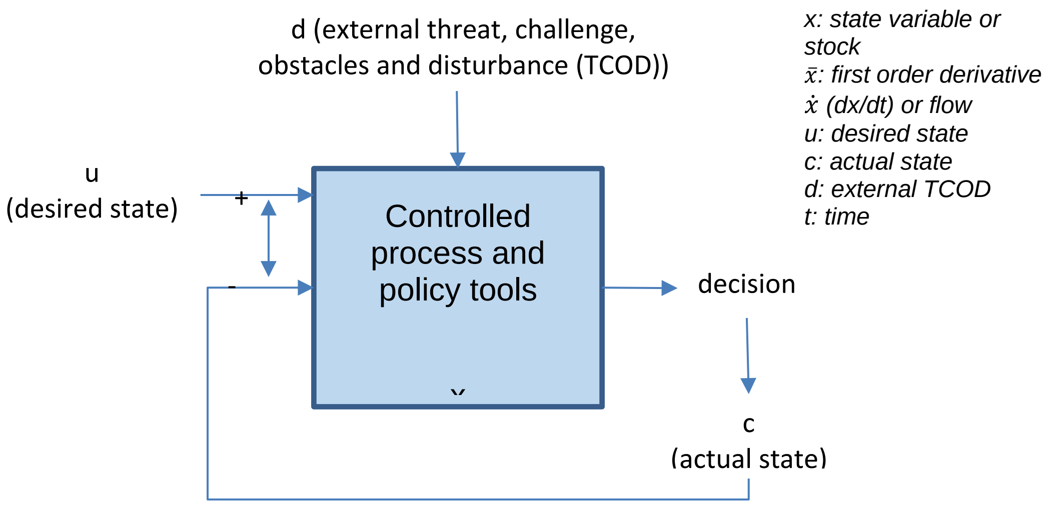
Thus, it is necessary to apply a modelling approach, especially systems dynamics modelling in the assessment of the utilization of marginal land and the appropriate conversion technology for increasing liquid fuel self-sufficiency in Indonesia.

3.2.3 Using systems dynamics modelling for policy analysis

Policy analysis has specific characteristics, such as the existence of dynamic behaviour of a state of condition which is influenced by a decision made, and the interrelationship between the policy and the performance. All of these exist for achieving a predetermined target, and policy modelling can help with a more powerful analysis of a policy, especially for simulating the interdependency between variables.

Shinners (1972) showed that the nature of dynamic phenomenon based on nature's law and the decision-making theory can be completely accommodated by a mathematical model that represents a control system. The phenomena consist of feedback, state variable, decision variable, and delay, which contribute to non-linearity (Fig. 3.3).

The characteristics of a policy assessment system can be represented by elements of a system dynamics model, such as (i) state variable is represented by a stock/flow/accumulator, and (ii) decision variable is represented by a flow/rate. The stock and flow diagram states explicitly the mathematics equation (1) and (2). Thus, the systems dynamics approach is capable of performing computer modelling of policy.



(1) $\dot{x}$ = f (x,u,d,t): state equation
(2) c = g (x,u,t); output equation

Fig. 3.3 A generic mathematical model as an assessment in a control system (Shinners, 1972)

Note:

1. *The equation for $\dot{x}$ (first-order derivative of x) accommodates the concepts of feedback, stock, flow and delay in a dynamic (social) system.*
2. *The form of f function accommodates nonlinear relationships in a dynamic (social) system and a policy (decision) structure.*
3. *The mathematics model completely accommodates the definition of a dynamic phenomenon.*

In this study, the assessed systems have properties which make systems dynamics approach suitable for the assessment. For example, it has cumulative variables such as the marginal land area developed for energy crop and the readiness level of the innovated technology. The cumulative variables are determined by rate variables, such as the progress rate of marginal land development for energy crop and the progress rate of technology readiness. The relationships between variables were built based on a causality which includes feedback loops. The behaviours are dynamic where the statement of the cumulative variables have a delay. The system shows non-linear behaviours by the existence of the cumulative variables, rate variables, delays, and internal feedback loops.

A policy analysis focuses on identifying the characteristics lags in the response to an intervention, trade-offs between sectors or between the short- and long-run effects of a policy, and forces that might arise to oppose or dilute a policy, rather than predicting the change in the present value of bioenergy performances resulting from the policy (Sterman, 1981).

An example of systems dynamics use in policy analysis was demonstrated by The United Nations for Environment Programs (UNEP) that set principles of an integrated policy-making in order to design green economy strategies (UNEP, 2014). It consists of several stages, namely issue identification, policy formulation, policy assessment, and policy monitoring and evaluation. In conjunction, each has several steps and indicators. The policy formulation step covers identification of desired outcomes, the definition of policy objectives, and identification of intervention options and output indicators. Similarly, the policy assessment step consists of identification of policy impacts across sectors, analysis of impacts on the overall well-being of the population, and analysis of advantages and disadvantages and inform decision-making. Furthermore, indicators are used for: problem identification which helps to frame the issue; policy formulation which helps to design solutions, and for impact indicators supporting the assessment of the cross-sectoral impact of the interventions chosen.

To assist countries with defining their green economy strategies, a green economy model was built by UNEP (2014) using system dynamics methodology as it has capability to provide:

- “what if” analysis to inform what are the impacts of a policy implemented at a specific time and circumstance;
- an understanding of what drives a behaviour;
- identification of real systems’ properties, particularly feedback loops, delay and nonlinearity, that are highly adjustable based on the system’s characteristics.

In this research’s context, the system dynamics principles are applied to design an integrated liquid biofuel strategy and to develop the model for the assessment.

3.3 A review of existing assessments of liquid fuel development strategy including feedstock and conversion technology

There was no study found that assessed bioenergy strategies for increasing liquid fuel self-sufficiency that considers marginal land to grow feedstock and the most appropriate technology for liquid biofuel production in an integrated manner.

A recent study on marginal and degraded land use for bioenergy by Cowie et al. (2018) proposed a conceptual framework for land degradation neutrality (LDN) focusing on the LDN goal and the processes to achieve it. The study described the interaction between biophysical and socioeconomic aspects and developed a framework for LDN planning, implementation, and monitoring consisting of multidisciplinary elements. However, the related simulation works have never been found in existing studies.

3.3.1 Existing studies on feedstock and technology for liquid biofuel production and use in Indonesia

Before 2018, two studies found regarding Indonesian liquid biofuel assessments that consider feedstock and the conversion technology in an integrated fashion. In both studies, the feedstocks were assumed grown on fertile land, and the conversion technologies were of the first generations. They also did not use the systems dynamics approach.

The first study was conducted by Rahmadi, Aye, and Moore (2013), which assessed the feasibility and implications of Indonesian liquid biofuel target in 2025. The liquid biofuel types covered pure plant oil, biodiesel and bioethanol, which are oxygenated types. The feedstock assessment did not explicitly consider the utilization of marginal land. For the assessment, the Long-range Energy Alternatives Planning System (LEAP) was used as a tool. LEAP is a scenario-based tool that applies the accounting framework rather than simulating decisions (Heaps, 2002). The modelling scenario for liquid biofuel demand was based on the historical trend of energy demand growth and the highest permissible mix level with petroleum oil fuel. The study assessed the possibility to meet the target by 2025 as set in national energy policy and how much land area will be required.

Another study was conducted by Jupesta (2012), which modelled technological changes in the biofuel production system in Indonesia. The study developed a model to optimize the net energy balance under land and technology constraints, using the General Algebraic Modelling System (GAMS) tool. Like the previous study, this study considered only oxygenated liquid biofuels and did not explicitly consider marginal land use in the modelling. The target of liquid biofuel demand was also based on existing national energy policy.

Unlike those studies that fixed the target of liquid biofuel demand as stated in national energy policy, the model developed in this research determined liquid biofuel demand based on an anticipative or future-based demand in liquid fuel. In 2018 early, part of this study was presented, emphasizing the importance of marginal land use for energy self-sufficiency in large archipelagic countries such as Indonesia (Lamria, Sims, Soerawidjaja, & Murray, 2018).

3.3.2 Existing studies on feedstock and technology for liquid biofuel production and use outside Indonesia

Outside of Indonesia, there are a few assessments of liquid biofuel development that use a system dynamics approach and considers feedstock and the conversion technology, such as in Columbia (Espinoza, Bautista, Narvaez, Alfaro, & Camargo, 2017), Iran (Azadeh & Arani, 2016), Latvia (Barisa, Romagnoli, Blumberga, & Blumberga, 2015), Malaysia (Applanaidu, Abidin, Sapiri, & Zabid, 2015), USA (Jeffers, Jacobson, & Searcy, 2013), and South Africa (Jonker, Brent, & Musango, 2015).

Like the existing Indonesian studies (Section 3.3.1), none of the studies considered the use of marginal land for growing feedstock nor the innovation in conversion technology for liquid biofuel production. Also, all of them did not consider an anticipative target in modelling liquid biofuel demand. On the other hand, this study includes an integrated strategy which involves the utilization of marginal land and technology innovation for drop-in biofuel production. This study also considered an anticipative target for liquid biofuel demand.

Although some of the existing studies use a systems dynamics approach, none of them treated policy as an endogenous variable. Hence, they did not show the interrelationship between political sustainability and liquid biofuel sustainability. Among bioenergy sustainability dimensions (MIT, 2015) and studied by Bautista, Enjolras, Narvaez, Camargo, and Morel (2016), politics and technology are the least assessed in the literature. On the other hand, the assessment in this study explicitly shows political and technological sustainability which interrelates to one another in the scope of liquid biofuel sustainability.

3.4 Development of a simulation framework using an Indonesian case study

Considering the reviews in previous section, a simulation framework was developed to perform the assessment. The framework describes the integration in the proposed strategy, and how their performance and policy inform to one another in achieving the desired state.

The proposed framework (Fig. 3.4) is built by four parts: (i) the proposed strategy, (ii) the actual state of liquid fuel self-sufficiency, (iii) the desired state of liquid fuel self-sufficiency, and (iv) the policy for influencing the strategy.

The preparation of the more appropriate technology is expected to be completed before oil feedstock from marginal land is available in the market. Thus, the progress in the innovated technology readiness influences the rate of marginal land development for energy crop.

It is shown that the preparation of the more appropriate technology and the oil feedstock from marginal land simultaneously determine the liquid biofuel supply, which influences the liquid fuel import demand, which in turn affects the preparation of the technology as well as the feedstock.

In achieving the desired state, the actual state of liquid fuel self-sufficiency informs the policy to adjust the intervention magnitude to the strategy system. It is shown that the policy and the strategy implementation affect one another. As an endogenous variable, the policy has an interrelationship with the achievement of liquid fuel self-sufficiency, and hence it can show political sustainability in the scope of liquid biofuel sustainability.

Unlike the existing studies that treat policies as exogenous variables and hence do not show political sustainability within the liquid biofuel sustainability scope, this study considered explicitly the political sustainability, which means the policy is generated by the system. The actual state of liquid fuel self-sufficiency influences the policy which leads to adjustment of the desired state of liquid fuel self-sufficiency as well as the strategy implementation, which affects the actual state of liquid fuel self-sufficiency, which in turn influences the policy itself.

Thus, the framework provides a better understanding of the assessed systems by explaining the interrelationship between liquid biofuel sustainability and political sustainability which is an important success factor of a liquid biofuel strategy.

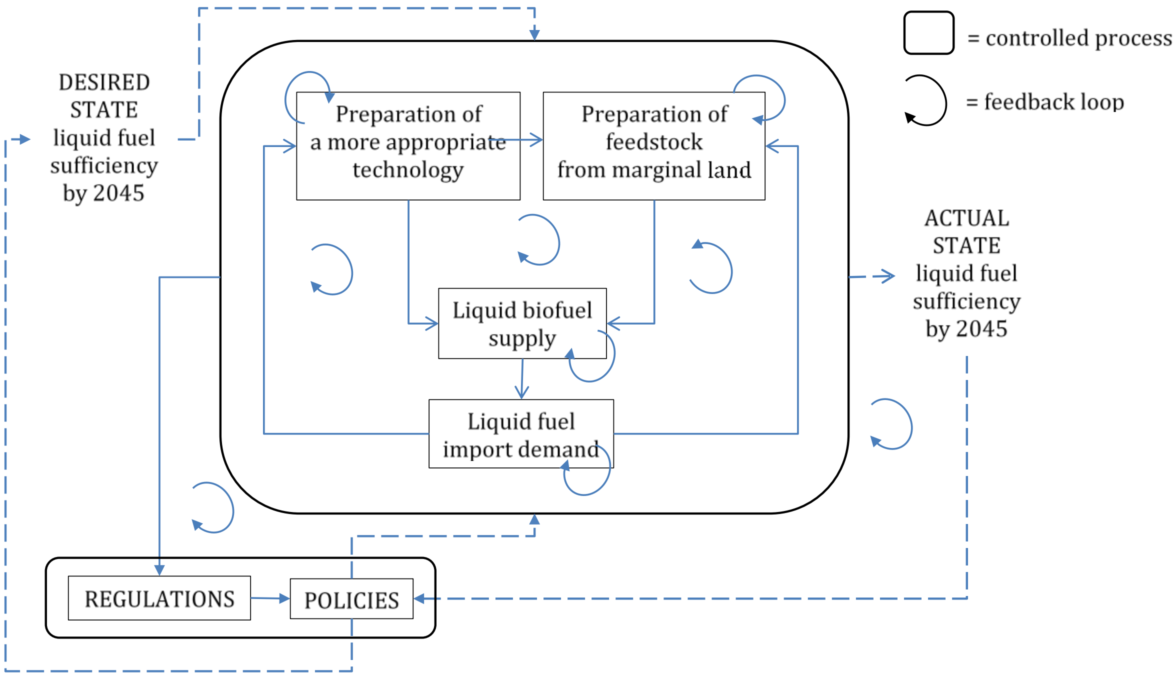


Fig. 3.4 Simulation framework for assessing the proposed strategy

The simulation framework is used in guiding the development of a systems dynamics model (Chapter 7) in the policy-making process.

In the next three chapters, marginal land use and appropriate technology will be assessed subsequently which outcomes will include proposing a specific type for the crop to grow on marginal land, and technology for liquid biofuel production. A case study island is taken to describe how the model implemented at the local level (Chapter 6).

3.5 Conclusion

The system of the proposed strategy has interdependencies between variables, therefore an integrated and modelling approach is required for the assessment. Systems dynamics approach was used for the assessment because it is well recognized for the capability of dealing with interdependencies, especially in policy analysis.

The proposed strategy is discussed for the first time by this research. Thus, the studies on both the proposed strategy and the assessment contribute to new knowledge, particularly in area of energy management and system theory.

The simulation framework implies that delay is a critical factor that determines the liquid fuel self-sufficiency in Indonesia through utilization of marginal land and innovation in conversion technology for liquid biofuel production.

CHAPTER 4

ASSESSMENT OF MARGINAL LAND USE AND CHOICE OF CROP FOR BIOENERGY IN INDONESIA

4.1 Introduction

Using marginal land to produce energy crops in archipelagic countries have significant benefits.

- It can support national energy security as well as energy self-sufficiency in small islands, through the provision of feedstock for liquid biofuel production and bioelectricity generation.
- If used for biofuels, it can strengthen the economy by reducing oil fuel imports as well as increasing households' income.
- It will support environmental quality through greenhouse gas (GHG) emissions mitigation.
- Through good management practice in using marginal land, the biofuel feedstock cost can be relatively low and more controllable, especially when grown on government-owned land area.

To get the benefits, it is important to consider several factors before cultivating marginal land: i) demand for liquid fuel; ii) suitability with soil and climate; iii) availability of marginal land; iv) strategic choice of plantation crop; v) strategic choice of energy conversion technology; vi) geographic location; vii) energy sovereignty; viii) long-term economic impact, and ix) GHG mitigation (Wargadalam et al., 2015).

This chapter provides an analysis of the potentially available area of marginal land for biomass production in Indonesia. It also gives an assessment of the most suitable energy crops to cultivate on marginal land and proposes the most promising one. The analysis provides inputs when developing a model for assessing marginal land use for growing the selected energy crop that includes a possibly available area and crop productivity.

Section 4.2 analyses marginal land potential in Indonesia and its various characteristics. The available land is distributed over the archipelago of which the portion that could be used for energy crop production can be determined.

Section 4.3 describes the degradation causes and restoration of marginal land. Understanding the causes of land degradation will help with implementing an appropriate technique for the restoration.

Section 4.4 proposes a suitable energy crop for growing on marginal land. Determination of a suitable energy crop before starting cultivation is crucial and should be carried out very carefully. A proper determination is important because the crop's growth is irreversible and it will take several years before yielding a product containing specific properties.

4.2 Analysis of marginal land potential in Indonesia

4.2.1 Rationale for using marginal land for energy crop

One of the difficulties in implementing biomass for energy is the possible conflict over conservation of land, water, and biodiversity (Slade, Bauen, & Gross, 2014). This conflict is not likely to happen if the land is marginal and a suitable crop is cultivated. Developing marginal land for growing energy crops can improve national energy security by providing feedstock for producing liquid fuels and electricity, and energy self-sufficiency, especially in small islands that lack crude oil reserves. It will support the local economy through socioeconomic aspects such as increasing household income, reducing oil imports, and achieving renewable energy targets. It will also benefit the environment through soil remediation and climate change mitigation.

The biomass demand for energy can be fulfilled by using the potentials consisting of the availability of marginal land, the existence of suitable energy crops, and the development of appropriate technology.

4.2.2 Criteria of marginal land

In Indonesia, either marginal land or degraded land is commonly called *"lahan kritis"* or "critical land". This is described as land area that has no further function in regulating the hydrology system and land productivity, and that, in turn, disturbs the watershed's ecosystem balance (MOF, 2013a).

This study uses the term "marginal" land as part of "critical" land in Indonesia, to emphasize the soil's condition that determines whether it is marginal for food crop cultivation or not. The land is assumed to be suitable for growing an energy crop. Due to data limitation, the marginal land area that was considered available for cultivation for biomass was assumed to be the two most severe types of critical land area, namely "very critical" and "critical". Then the land which can be identified as marginal for food crop production will be considered having potential for growing an energy crop.

All aspects of types and causes of land degradation are important in determining suitability and availability of marginal land for biomass production. In determining the availability, it is also necessary to assess the locations of land that can be categorised marginal, the projected time to start cultivation, and whether they can be sustainably used for growing energy crop. Two important challenges to overcome are:

(i) the difficulty and cost in reducing the level of degradation that can take many years and even then, the final productivity is still low; and
(ii) some degraded lands are used for significant purpose by poor people who have no formal land rights (Wicke, Smeets, Watson, & Faaij, 2011).

Locations of "critical" lands throughout Indonesia were presented in detail in a technical guideline (Table 4.1). This guideline determined maximum area of marginal land that is potentially available for growing energy crops, as input to the system dynamics model (Chapter 7).

The degree of "critical" land severity in Indonesia was determined by the Ministry of Forestry (MOF, 2013b) based on an assessment of five parameters: land coverage, slope, erosion risk level, productivity, and management. Scores for each criterion were put on a map then overlaid to produce an overall map that shows the level of severity through calculation of the total score by a weighted average method. Data collected to build the map comprised:

- rainfall data of watershed in last ten years;
- soil data to determine erodibility value;
- terrain, and
- plantation management and soil conservation.

Supporting data was also used, such as (i) soil effective depth; (ii) sedimentation; (iii) minimum, maximum, average, flooding, and peak of water flow rate, and (iv) agricultural intensification. Taking account of the land location, whether it is in a forest protected area, agriculture area, or non-forest protected area, the guideline map gives five levels of severity: i) non-critical; ii) potentially critical (light); iii) quite critical (moderate); iv) critical (severe), and v) very critical (extreme) (MOF, 2013a, 2013b).

The total critical land area was approximately 70 Mha which consists of slightly critical, critical and very critical (Table 4.1, Fig. 4.1) that is distributed in all islands. Rehabilitation was focused on the very critical and the critical land areas, which are around 5Mha and 20 Mha respectively (Table 4.1) (MOF, 2015). This represents around 13% of total land area.

Table 4.1. Area (ha) of land at various stages of degradation by province in Indonesia (MOF, 2015)

No	Province	Not criitcal	Potentially critical	Slightly critical	Critical	Very critical
1	Aceh	757,698	3,374,853	989,528	474,664	150,694
2	North Sumatera	2,603,200	1,465,550	2,133,820	580,944	478,523
3	West Sumatera	667,315	2,261,254	745,072	485,907	144,789
4	Riau	273,559	3,385,218	3,211,537	1,737,809	151,813
5	Riau Islands	5,193	216,529	265,889	224,031	114,177
6	Jambi	2,133,634	835,473	1,157,155	515,192	264,582
7	Bengkulu	269,035	638,130	525,297	586,026	135,648
8	South Sumatera	3,890,789	2,480,761	1,821,722	299,172	13,692
9	Bangka Belitung	41,062	426,619	987,733	155,388	60,720
10	Lampung	1,345,425	1,181,776	617,911	238,322	84,602
11	Banten	320,472	358,663	218,213	33,239	3,716
12	DKI Jakarta	64,295	316	78	-	-
13	West Java	1,402,053	926,942	1,044,745	302,014	40,952
14	Central Java	1,831,998	917,565	591,900	105,633	5,210
15	DI Jogyakarta	163,604	57,831	67,254	25,272	845
16	East Java	1,658,816	1,027,083	904,700	485,042	736,877
17	Bali	259,334	141,805	112,352	43,087	2,910
18	West Nusa Tenggara	111,131	1,275,700	400,730	154,358	23,219
19	East Nusa Tenggara	759,024	1,234,509	1,694,025	942,976	17,878
20	West Kalimantan	780,547	9,834,598	2,779,565	752,711	106,864
21	Centra; Kalimantan	1,157,573	5,569,118	3,456,300	4,785,299	359,405
22	South Kalimantan	260,802	1,579,774	1,327,309	508,941	132,645
23	East Kalimantan	1,125,789	3,821,311	6,866,318	847,590	63,230
24	North Kalimantan	1,379,592	3,776,487	2,024,451	245,215	29,125
25	North Sulawesi	149,883	414,533	640,626	189,816	79,395
26	Gorontalo	222,049	273,360	161,347	319,393	247,244
27	Central Sulawesi	2,863,903	1,811,562	934,457	347,955	104,277
28	West Sulawesi	239,023	751,847	394,228	263,404	55,749
29	South Sulawesi	652,296	1,609,559	1,658,935	388,509	144,152
30	South East Sulawesi	207,180	850,340	1,661,227	631,628	313,477
31	Maluku	612,775	1,562,842	1,716,987	471,015	257,761
32	North Maluku	93,808	1,303,660	1,333,395	322,948	97,153
33	West Papua	472,792	7,491,110	1,428,813	128,244	50,997
34	Papua	26,708,698	790,576	2,004,847	1,973,165	266,064
	TOTAL	**55,484,347**	**63,647,254**	**45,878,466**	**19,564,909**	**4,738,385**

Fig. 4.1 Distribution of critical land in Indonesia in 2013 (MOF, 2015)

4.3 Causes and restoration of marginal land

Land can be categorized into used and unused and the latter can be further classified into abandoned cropland, degraded land, idle land, marginal land and wasteland (Wiegmann et al., 2008).

Land degradation is commonly caused by human misbehaviour in land use (Bergsma et al., 1996). There are several reasons for degradation such as erosion, soil fertility decline, waterlogging, salinization, subsidence, deforestation, forest degradation, rangeland degradation, soil pollution, and soil destruction (FAO, 1994). In general, the main symptom of land degradation is lack of nutrient that causes limitation in nutrients, water, toxicity, agronomy and gaseous exchange (Oldeman, Hakkeling, & Sombroek, 1991).

Land categorised as marginal for a certain crop might not be marginal for another crop depending on the degradation process and whether the soil condition is insufficient to sustain cultivation of a planned crop (Chapter 1).

4.3.1 Causes of marginal land

The causes of land degradation can be classified into biological, chemical, and physical/mechanical factors:

- Biological causes:
  - Overgrazing and over-drafting by livestock
  - Monoculture vegetation that destabilizes the local ecosystem.
- Chemical causes:
  - Soil contamination by chemicals, pesticides, factory waste, and artificial radioactivity due to agricultural, industrial, mining or commercial activities.
  - High acidity.
  - Increased salinity.
- Physical/mechanical causes:
  - Soil structure destruction due to inappropriate mining activities, vehicle off-roading, or soil expose by heavy equipment in post-harvesting.
  - Erosion, driven by water, wind, or mechanical force.

- Waterlogging due to inappropriate irrigation.
- Forest logging.
- Over-drafting due to inappropriate irrigation.
- Continuous puddle.
- Weather, for example, dry weather and water freezing.
- Loss of arable land, for example, land clearance through clearcutting and deforestation, urban construction, nomad farming,
- Soil contamination by non-biodegradable trash.

Degraded lands are often characterized by acidic pH, low levels of key nutrients, poor soil structure, and limited moisture-retention capacity (Palumbo et al., 2004), so that to grow plants on them, levels of soil, water and carbon/organic matter must be sufficient and maintained in order to preventing further degradation and supporting reclamation (Victoria et al., 2012).

4.3.2 Restoration of marginal land

Land degradation which is not caused by water nor wind erosion is generally reversible through proper actions which are usually very costly and workforce demanding, such as in reclaiming salinized and waterlogged irrigated areas (FAO, 1994). The cost of restoring degraded land can be at least 100-fold more costly than doing prevention . Therefore, it is crucial to minimize delay because it will increase the cost of rehabilitation.

As land restoration is a time-consuming process, the utilization for energy crop production should be prepared as early as possible. To exemplify, Indonesia is now producing liquid biofuel from palm oil surplus which is constrained by the demand for food purpose. Therefore, utilizing the potential marginal land to provide liquid biofuel feedstock should be planned and prepared well to enable biofuel production to meet future needs when palm oil production becomes more important for food purpose.

Marginal land can be rehabilitated through technical and managerial methods those aim mainly to improve the biological, chemical and physical soil properties and the plant productivity. The technical methods consist of biological, chemical, and physical/mechanical methods.

a) Technical methods:

- Biological techniques:
  - Planting vegetation on as much as a land area to minimize erosion by wind and water, and to improve the soil properties through rebinding soils and providing nutrients.
  - Planting vegetations that can fix nitrogen from the air, such as leguminosae to loosen soil and increase soil fertility (Rhodes, Askin, & White, 1982).
  - Planting vegetation that grows rapidly and can maintain slope stability.
  - Adding fungi to support plant/organic material decomposition, strengthen soil structure and enhance plant growth (Singh, Vaish, & Singh, 2016).
  - Developing a heterogenous cropping and crop rotation to increase soil fertility and avoid erosion (Gómez et al., 2018).
  - Applying plant residues for increasing organic matter.
- Chemical techniques:
  - Applying biochar for improving soil health by lowering pollutant concentration and increasing nutrient and water retention, and plant productivity.
  - Addition of chemical fertilizers for replacing soil nutrients.
  - Applying soil conditioner for strengthening soil aggregates.
  - Adding bitumen for improving soil structure.
  - Using lime for neutralizing acidic soil.
  - Adding sulphur for neutralizing alkaline soil.
  - Combined application of coal combustion by-products with organic amendments to support C sequestration and improve soil fertility (Palumbo et al., 2004).
  - Adding ash from a biomass power plant to enrich potassium content.
  - Ash treatment to decrease soil acidity (Ågren & Löfgren, 2012) and increase soil respiration and plant growth (Dong, Kirk, & Tran, 2014).

When the ash comes from biomass fuelled boiler, it will return cations such as Ca, K, and Mg, and this could avoid ion depletion from the soil, that will affect biomass production for the next growing cycle (Williams, 1997).

  - Salinity control and reclamation projects which is very costly (FAO, 1994).

- Physical/mechanical techniques:
  - Zero tillage farming, the direct sowing of seeds with minimal disturbance to land (FAO (2019); Langdale, West, Bruce, Miller, and Thomas (1992)).
  - Building swales on steep slopes and in irrigation to avoid further erosion.
  - Land conservation by establishing contour lines, contour ploughing, forming bumps, irrigation through water channels, and building reservoir.
  - Removal of non-biodegradable material such as plastic.

b) Managerial methods:

- Human management.
- Law enforcement to land degradation actors.
- Integrated management in marine area and watershed.
- Range management in degraded pastures (FAO, 1994).
- Water management to improve productivity, e.g. irrigation.
- Treatment of residue ((Lapola, 2010); (Bondeau et al., 2007)).
- Resting land for several years before being productive again, such as in reclamation forestry (FAO, 1994).

Time for restoring values from degraded land depends on the ecosystem type, land use pattern, climatic variations, and the benefits to expect (Daily, 1995). For a successful degraded land utilization, it is important to anticipate the need for significant investment in establishing sufficient infrastructure and restoring the soil. Incentives from the government would be critical to attract investment (Sims, Mabee, Saddler, & Taylor, 2010).

4.4 Choosing an energy crop for marginal land

4.4.1 Rationale for choosing an energy crop

It can take 5-10 years to develop a new energy crop until it is ready to plant and employ (Soerawidjaja, 2011). Activities that take significant time include (i) government decision and coordination as this is a multi-sectoral and multi-regional strategy; and (ii) growing the energy crop until harvesting for oilseeds and wood fuel (Chapter 3). Therefore, choosing a suitable plant species should be undertaken conscientiously.

Some common failures in the past for using marginal land for energy crop were the low and uncertain productivity that made feedstock costs too high (Section 4.5). One of the solutions to this problem is to choose an appropriate crop to support the success and sustainability of the project as each type of crop has permanent properties impacting all the crop lifetime.

4.4.2 Potential crops

Biomass potential (Chum et al., 2011) can be grouped into:

- theoretical potential, the total biomass stock which is restricted by its biophysical characteristics;
- technical potential, taking into account the limitations of implementation of biomass production, simultaneous demand for food, feed, fibre, forest products and human land use. This potential can also consider constraints of protection of nature and soil/water/biodiversity when the term is commonly called sustainable potential; and
- market potential defined as the portion of the technical potential which is possible to be produced in certain conditions to make economic benefit. Besides production cost, this is also determined by other factors that include the typical conversion technologies, the cost of competing for energy technologies and the existing policy system.

In maximizing market potential of a crop used for biofuel production, it is important to make sure of the feedstock readiness and the support for self-sufficiency through government policy. For sustainability concerns, energy crops on marginal land in Indonesia are expected to have capabilities of (Wargadalam et al. (2015), Amigun and Musango (2011)):

- growing well on land that is unsuitable for cultivating the main oil crop such as oil palm in Indonesia, to avoid land use competition. It means that unlike oil palm, the crop candidates should grow well on lands that are less fertile and have low rainfall. The types of marginal lands in Indonesia include dry lands and near sea lands. The crop should also ideally be non-toxic, non-weedy, and adaptable to various environmental areas.
- producing non-edible oil for liquid biofuel feedstock, to avoid competition with food purpose. Accordingly, the important factors include (i) feedstock productivity; (ii) biofuel yield; (iii) suitability for various biofuel use that will increase the level of substitution to associated fossil fuel, and (iv) fatty acid composition of vegetable oil that is useful for predicting the quality of liquid biofuel.
- multi-purpose or more added-value from non-oil parts, to make it more competitive with palm oil, especially the capability for producing energy-grade fuelwood for fuelling bioelectricity generators both the existing and the upcoming ones. Other purposes include providing feeding or fodder, fibre, rubber, medicinal substances, bioactive chemicals, and pesticide. This capability will also minimize land requirement and in line with the global shift towards a bio-based economy.

Table 4.2 shows a comparison of several crops that are potentially suitable for cultivation and have been found growing on Indonesian marginal land, based on suitability criteria of an oil-bearing crop, especially the oil productivity and whether the crop produces high energy wood, fixes nitrogen, grows fast, and can grow on land contaminated with salt from brackish or sea water.

Regarding low impacts to soil and water resources, suitable oilseed energy plantations for dry climates include *Jatropha curcas*, *Simmondsia chinensis*, and *Pongamia pinnata* (Cushion, Whiteman, & Dieterle, 2010). Based on the desired characteristics for energy crops (Table 4.2), only *Pongamia pinnata (L.) Pierre* meets all of them (Cushion et al. (2010); Kazakoff, Gresshoff, and Scott (2011)).

Table 4.2. Key characteristics of potential energy crop for Indonesian marginal land

Crop non-edible oil [a,d]	**Oil productivity achievement (kg/ha/yr)**	**High energy wood**	**N2 fixing**	**Added values to non-oil parts**	**Fast growing**	**Can stand on salty/sea water**
Azadirachta indica	2,670 [a]	Yes	Yes	Yes	No	No
Calophyllum inophyllum	4,680 [a]	No	No	Yes	Yes	Yes
Jatropha curcas	2,500 270 in India 480 global average 1,620 best [a]	No	No	Yes	No	No
Pongamia pinnata	up to 6,750 [c] 5,499 [b] 2,000-4,000 in India [b]	Yes	Yes	Yes	Yes	Yes
Ziziphus mauritiana	1,371 [a]	No	No	Yes	No	No
Schleichera oleosa	No data	Yes	No	yes	No	No
Simmodsia chinensis	1,950 [b]	No	No	Yes	No	Yes

[a] Azam, Waris, and Nahar (2005)
[b] Cushion et al. (2010)
[c] Murphy et al. (2012)
[d] Soerawidjaja (2010)

4.4.3 Pongamia pinnata

Pongamia, a leguminous tree with height up to 15-25 m (Fig. 4.1), is native to many countries in South Asia, North Australia and Pacific islands, such as India, Indonesia, Malaysia, and Myanmar (Cushion et al., 2010, p. 199). It has many local names in Indonesia such as Malapari, Mabai, Ki Pahang Laut, Bangkong, Kranji, Butis, Sikam, Asawali, and Hate hira (Soerawidjaja, 2016b).

The taxonomy of pongamia is (NBC, 2015):

Kingdom : Plantae

Phylum : Tracheophyta

Class : Magnolopsida

Order : Fabales

Family : Fabaceae

Genus : Pongamia

Pongamia is considered to be the most suitable energy crop for marginal land based on various impacts on economy, social and environment (Cushion et al., 2010). As well as having the desired characteristics, pongamia has been well researched with much data available for input to the model developed in this study (Chapter 7).

4.4.3.1 Properties

Pongamia is not an invasive species and is widely spread (Cushion et al., 2010). pongamia trees yield energy feedstock in forms of oilseeds and high energy wood. Oilseed production is reliable up to year 50; the first harvest is at 3-5 years old, and the peak yield is in the 9-11th year (Murphy et al., 2012) with oil content up to 40%. The woody biomass has a high calorific value of 19 MJ/kg (Duke, 1983) that makes it suitable for fuelling biomass power plants.

Fig. 4.2. Five year old pongamia tree plantation growing on critical land at Parung Panjang, West Java, Indonesia. (February 2016)

The physico-chemical properties of pongamia oil (Table 4.3) enable it to be easily converted into biodiesel (fatty acid methyl ester – FAME) that meets the standards EN 14214 and US ASTM D 6751-02 and is satisfactory for production in tropical countries. The challenge is its oxidative stability, cold-weather performance (cloud point), and ignition performance (Kazakoff et al., 2011). As feedstock for drop-in biofuel production, it has a suitable fatty acid composition and iodine value (Chapter 5).

Table 4.3. Physico-chemical properties of pongamia oil at time of harvest (Wargadalam et al., 2015)

Parameter	**Value**
Oil fatty acid composition (%)	
Miristic acid	3.7-7.9 %
Stearic acid	2.4-8.9 %
Oleic acid	44.5-71.3 %
Linoleic acid	10.8-18.3 %
Arachdiat acid	2.2-4.7 %
Alpha-eleostearic acid	1.1-3.5 %
Water content	0.1 %
Specific gravity	925 kg/m^3 @15^{o}C
Kinematic viscosity	2-6 mm^2/s @30^{o}C
Acid value	2 mg KOH/gr
Iodine value	105 g Iod/100 g

Domestication of pongamia is supported by the crop characteristics such as regular annual cultivation, plant uniformity, oilseeds and oil productivity, oil structure and consistency, fast and erect grow, seed dispersal, resistance to pest and infection, flowering phase, nitrogen fixation, efficient water consumption, and endurance to a wide range of climate and soil condition (Kazakoff et al., 2011).

4.4.3.2 Land suitability

Saline and drought-tolerance make pongamia a suitable crop for some marginal lands where these are issues (Daniel (1997) in Cushion et al. (2010, p. 202)). Its optimum planting locations in Indonesia are distributed in Sumatera, Java, Kalimantan, and Timor islands. For some of the plantations, the oilseeds have been recently been harvested. For example, on reclaimed mining land of PT Adaro Tanjung the first harvest was undertaken in the third year in 2017, and a government's owned critical land in Parung Panjang was first harvested in the fifth year in 2016.

a) Climate

Pongamia can grow well under precipitation between 500 – 2,500 mm. Having a deep root structure makes it drought tolerant since it can take up water and nutrients more effectively. Pongamia can also survive in temperatures between 0-50^{o}C and grow up to 1,200 m above sea level (Duke (1983) in PurdueUniversity (1998)).

b) Soil

Pongamia can grow well on most soil types including sodic acid, alkaline, heavy clay with a sodic subsoil; stony, sandy, clay, coastal, and saline habitats. However, the plant does not grow so well on dry sands (Murphy et al., 2012).

Planting pongamia on alkaline soils can increase nitrogen, phosphorous, and potassium content in the leaves (Kaushik, 2015). Being leguminous, the capability to produce nitrogen can improve soil quality.

Pongamia also has a dense root structure that can help reduce the risk of soil erosion. (Cushion et al., 2010).

4.4.3.3 Cost and Productivity

Economic profitability is the principle goal for farmers in terms of $/ha gross margins. However, this plant is not familiar to most Indonesian farmers so, to reduce risk in the investment, training is required such as in:

- using only certified high-yielding seeds;
- undertake comparative investment calculations;
- planting multi-species with each having different harvesting seasons;
- application of mechanical harvesting techniques; and
- establishing and optimizing block plantations system (Altenburg et al., 2009).

Australia is one of the most advanced countries undertaking pongamia oil research for use as biofuel and has established several research areas. For example, in Western Australia a pongamia field has been grown since 1999. Another location is in Roma, Central Queensland, that was established in 2010 on 300 ha of coal seam gas site, which was the largest commercial trial site.

An advanced research was conducted through a collaborative research project that involved the University of Queensland (Murphy et al., 2012). The project was conducted on various pongamia planting sites both in Australia and other countries to assess pongamia prospects. Key data and information about pongamia productivity which were resulted from the research is summarized in Table 4.4. Soil characteristics of the cultivation trial locations include sodic acid, alkaline, heavy clay soils, and beach sands. Each hectare grows 320-500 trees and produces around 7 t oilseeds /ha/yr on average.

Table 4.4 Pongamia productivity based on Australian field trial research and observations (Murphy et al., 2012)

Variable	Unit	Range based on all observations in Australia	Average
Time to reproductive maturity	Years	4 to >14	5
Full development of oilseeds	Months	10-11	10
Flowering episodes/year	Number	1-2	1
Seed production per tree	kg/yr	0-30	20 (a)
Seed oil content	%	31-45	40
Seed viability	Months	<12	
Trees per hectare	Number	320-500	350 (b)
Oilseeds yield estimate (if all trees are productive)	t/ha/yr	n/a	7 (calculated from (a) and (b))

The study provided growth patterns of the oilseeds (Fig. 4.2) which is adopted as inputs to the model developed in this study, after assessing climate and soil suitability between a reference site and the sampling sites in the case study island (Chapter 6).

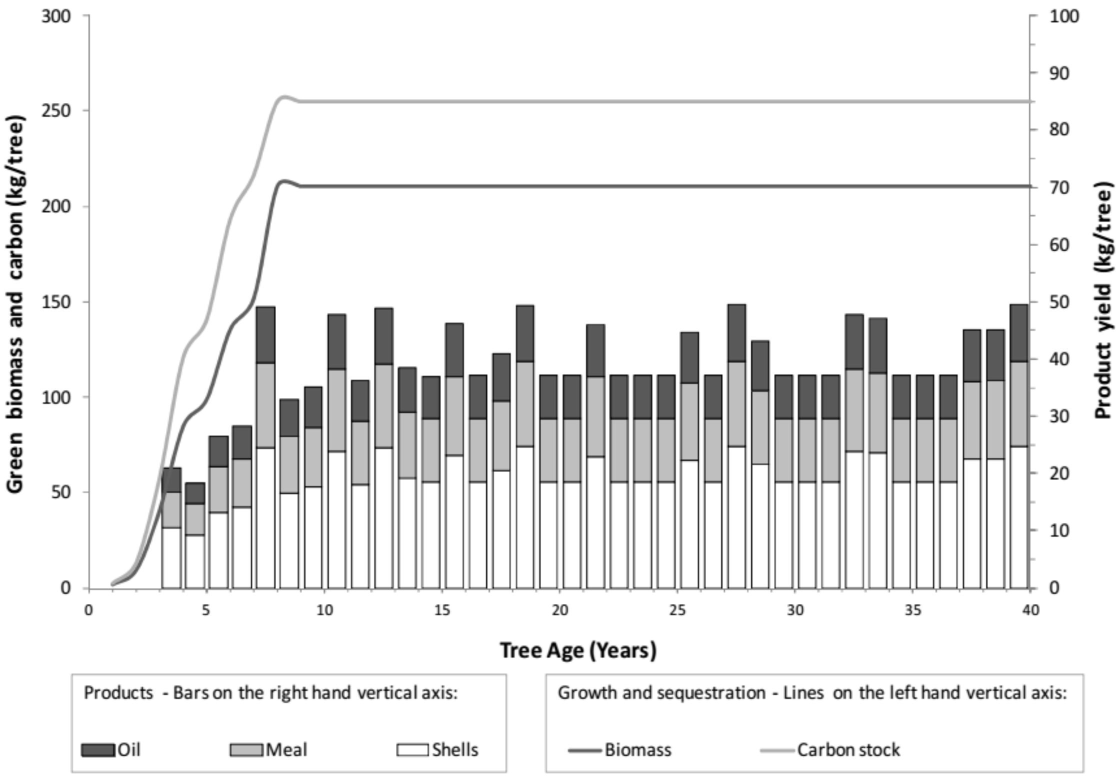


Fig. 4.3 Pongamia growth patterns over a 40 year period (lines, left-hand axis) and product yield (bars, right-hand axis). These estimates were used in the economic model for a scenario with the yield at an average of 20 kg seeds/tree/year (Murphy et al., 2012)

Although the research results have limitations that need further examination, they provide sufficient evidence of investment viability and potential for pongamia production (Murphy et al., 2012).

4.4.3.4 Competition to non-energy use

The energy production from crops should not disadvantage the more important uses. Using marginal land to grow energy crops will provide bioenergy feedstock and avoid competition with land use for food crops that cannot be successfully grown on such land. Also, pongamia oil is non-edible so that it will also avoid the conflict between energy and food uses. It will also avoid the impact on direct land-use change to GHG emissions.

4.4.3.5 The multipurpose capability of non-oil parts

Pongamia has other uses of its non-oil components that can generate added-value and household income.

a) Woodfuel

The common "failures" in cultivating oil-bearing crops on marginal land is that the time to the first harvest is longer than expected, and the oil productivity per hectare is too low or insignificant. In case of such failure falls on pongamia crop land, revenues could be still generated as Pongamia also produces high energy wood that can be sold to bioelectricity plants or cooking fuel.

b) Animal feed

Pongamia leaves can be eaten by livestock, while the meal or seedcake remaining after oil extraction can be used as an animal feed protein ingredient. Pongamia plantation and livestock farming can be integrated to improve sustainability.

c) Other uses

Other uses of pongamia include (i) green manure (Kaushik, 2015); (ii) medicinal use of flowers, leaves, and roots (Koshia, 2010); (iii) bio-based chemicals from the seedcake and (iv) as a shade tree or ornamental plant (Kaushik, 2015).

Proper utilization of the non-oil parts will give additional revenue, and thus DBF production from pongamia oil will be more economically attractive.

4.4.3.6 Environmental impacts

Pongamia cultivation on marginal land can have positive impacts on the environment, such as soil improvements, water quality, reduced biodiversity loss, and carbon sequestration.

a) Soil

The first benefit to the soil is the dense root structure that helps avoid soil erosion especially on steep lands, that reduces the risk of soil and any related chemicals slipping into water bodies. The other benefit is that the trees can fix nitrogen to support soil restoration by loosening the soil particle structure, increasing soil fertility, and thus improving future plant productivity. Moreover, it can enrich the contents of phosphorous, potassium, soil carbon and soil organic matter, for increasing soil fertility. (Altenburg et al. (2009); Drinkwater, Wagoner, and Sarrantonio (1998)).

b) Water

Considerations when selecting crops to be grown in dry areas are water uptake (evapotranspiration rates), levels of water demand, and biomass yield production (Kaushik, 2015). Pongamia productivity is significantly affected by water consumption (Kumar, Nautiyal, and Negi (1996) in Kaushik (2015)). Therefore, managing water is crucial when managing cropping land (Popp, 2014). Pongamia has a long root structure to improve water uptake from soil that makes it more saline resistant and drought-tolerant.

c) Biodiversity

Developing hetero-culture is very important for resistance to the pest of a broad plantation. To support hetero-culture and to give interim income between the harvesting seasons, Pongamia can be planted together with other oil-bearing trees that have different harvesting season or intercropped with annual crops that can also generate additional income for farmers while waiting for pongamia harvest season. The crop is also suitable for silvopasture technique (Soni, Subbulakshmi, Yadava, Tewari, & Dagar, 2016).

d) Carbon sequestration

The potential benefit of growing pongamia for GHG mitigation by removing carbon dioxide from the atmosphere is significant. Carbon is sequestered as a result of:

- biomass growth through:
  - increasing soil carbon by nodulation and root growth.
  - the ability for short rotation (a few years after the first harvest production in year 3-5).
  - productivity period of oil up to 40 years and living biomass up to 100 years (Rahman, Ahiduzzaman, Islam, & Blanchard, 2014).
- substituting for fossil fuels.
- reducing fertilizer manufacture.

GHG mitigation potential is 30 ton of carbon per ha where aboveground biomass and carbon is estimated four times the underground (Bohre, 2014). The less short-rotation cycle speeds up the carbon sequestration until reaching the maximum level, and thus supports the realisation of GHG emissions reduction target.

4.4.3.7 Potential from growing pongamia on marginal land-based feedstock

To calculate crop and energy potential from pongamia that is grown on marginal land, main data required are available area and crop productivity (Hoogwijk, Faaij, Eickhout, de Vries, & Turkenburg, 2005). Available area is determined by the proposed land cover that depends on land-use categories and land demand allocations. Crop productivity depends on terrestrial vegetation which is determined by potential crop and soil quality.

Crop yield from marginal land is affected by the cause of degradation and the degree of severity (Oldeman et al., 1991). Levels of degradation can be determined from the yield reduction percentage: light (5-15% yield reduction), medium (18-35%), strong (50-75%), and extreme (100%) (Nijsen, Smeets, Stehfest, and Vuuren (2012); Crosson (1997)). The more severe the land degradation, the less sensitive the productivity reduction is for perennial crops compared to annual crops (Nijsen et al. (2012); Crosson (1997)). Productivity is also determined by harvest index, CO_2 concentration, growing period (cloudiness, temperature, soil moisture (precipitation)), soil reduction factor (fertility, salinity, root depth, acidity), and management factor (Hoogwijk et al. (2005); (Agus, 2018)).

Of the total around 25 Mha of marginal land in Indonesia (Section 4.2), if 20 Mha could produce average pongamia oil yields of around 3 t/ha/yr, around 60 Gl per year of liquid biofuel feedstock could be produced.

It is possible to improve pongamia productivity on marginal lands, such as through land management, water availability, feedstock management and technological improvement (Deng, Koper, Haigh, and Dornburg (2015); Smeets, Faaij, Lewandowski, and Turkenburg (2007)).

Land management includes irrigation, residues treatment, intercropping (Lapola (2010); Bondeau et al. (2007)) and combined agroforestry and silvopastoral techniques (Dornburg et al. (2010) and Batidzirai (2013)). These influence productivity, soil organic carbon, and carbon emissions. Water availability in dry land is an important factor for biomass productivity, which is affected by the water use efficiency and the precipitation pattern (Dornburg et al., 2010). Feedstock management covers the cultivation of localized feedstocks, feedstock collection, processing and distribution (Green, 2016). Technological improvement can be applied through using higher quality seeds; increasing harvesting technologies; biotechnological advancement, and agricultural technological learning. (Batidzirai (2013); Dornburg et al. (2010))

Improving farming technologies seems to be challenging in developing countries, and it is important to study the implementation techniques (Dornburg et al., 2010). For example, Indonesian palm oil production can be increased from average 3.8 t/ha/yr to 7.0 t/ha/yr through using higher quality varieties and improving management practice (MOA, 2016). Therefore, implementing good pongamia cultivation techniques on marginal land is important for optimizing productivity.

In supporting a sustainable bioenergy production system, it is necessary to implement integrated policies for managing energy, land use and water (Popp, 2014). It is also important to accommodate heterogenous crops with each type based on land type and condition, interest, and impact (FGP (2016); MRTHE (2017)).

4.5 Model inputs

This chapter provides inputs for the model in Chapter 7, especially related to pongamia crop. The cultivation properties were set for (Section 4.4):

- Count of trees per ha: 350.
- Crop rotation cycle for reference mode: 15 years.
- Time length from cultivation to first harvest: three years.
- Oilseeds content: 0.4 kg oil / kg seed.
- The trees growth and the oilseeds yield of different ages as shown in Table 4.5.

Table 4.5 Trees growth and oilseeds yield of trees at different ages

Trees age (years)	Trees growth (t/tree)	Oilseeds yield (t/tree)
1	0.0005	0
2	0.0025	0
3	0.017	0
4	0.025	0.01
5	0.03	0.01
6	0.02	0.013
7	0.045	0.014
8	0.025	0.025
9	0	0.025
10	0	0.025
11	0	0.025
12	0	0.025
13	0	0.025
14	0	0.025
15	0	0.025

4.6 Lessons learned

A few commercial-scale projects of marginal land use for energy crops have been tried in India, Senegal, and Indonesia. Although for various reasons none have been successfully performed, several lessons can be learnt to minimize any risk or failure in future implementations.

4.6.1 Tree-borne oilseeds policy for biofuels in India

India launched the National Mission of Biodiesel (in 2003), National Biofuel policy (in 2009) and National Agroforestry Policy (in 2014) to reduce the country's high dependence on oil imports. Land use that integrates subsistence, environment and energy security was assessed (Dhyani, Devi, and Handa (2015); Rao, N.N.Reddy, I.Srinivas, and Dixit (2012)). The tree borne oilseeds (TBO) policy is a massive program for gaining non-edible oil from plantations grown on wastelands of which India has 55 Mha (Rao et al., 2012).

In Andhra Pradesh State, research commenced in 2004 to cultivate three plant species in 2007 that were determined through collaborated research: *Jatropha curcas, Pongamia pinnata,* and *Simarouba glauca*. The plantations were grown on wastelands where irrigation was hardly possible (Rao et al., 2012). The average rainfall of Andhra Pradesh is 940 mm per annum (AndraPradesh, 2014). The results showed that plants survived with oil yields much lower than expected, such as Jatropha 0.5-0.8 t/ha/yr and pongamia 0.6-1.1 t/ha/yr. This program was evaluated by (Rao et al., 2012) after five years of running. Concerns that contributed to the failure of the program in India included:

- economics of cultivation,
- inter-cropping,
- yield and price guarantee,
- areas proposed for plantations,
- procurement of seed or seedlings,
- timeframe to prepare degraded land utilization,
- land location and ownership, and
- consistent quality seeds for domestic use instead of from wild plants.

Even though the past projects have not been satisfying, the Indian government keeps serious efforts to improve the program in light of the huge potential of degraded land use for increasing their energy security (TheTimesOfIndia, 2013).

4.6.2 Jatropha project for biofuel supply in Senegal

The program was aimed at overcoming the lack of supply and the uncertain price of energy, developing the local economy, and increasing agricultural production through degraded land use.

Similarly to India, a large project using degraded land for energy crop was preliminarily studied with consideration of similar cases in other countries. The study identified three important factors (i) the crop's suitability to the local climate that affected the productivity; (ii) integration of a national plan with smallholders and economic fairness for both farmers and buyers, and (iii) support of policy framework for an infant biofuel industry including policy consistency, development organizations, and interest rates (Campbell, 2014). For future implementation, the study recommended that specific economic schemes and innovative financing alternatives focusing on the community are necessary.

STAP (2015) assessed that the main cause of failure in Jatropha cultivation for biofuel purpose was the quality variability and seed availability. In term of financing smallholders for biomass production from degraded land use, it was suggested to utilize cooperatives and small farmer organizations that can provide benefits from lessons learned as well as financial profit.

4.6.3 Jatropha project for marginal land use in Indonesia

Promotion of Jatropha cultivation on marginal land in Indonesia for liquid biofuel feedstock boomed in the last decade. This was due to the rising global issues on climate change, the 2005-2006 crude oil price peaking at around US$145 per barrel, and the role of cross-sectoral actors including engineers and policymakers. The project was driven by spreading news and claims via the internet as well as building a public expectation of oil yields (Afiff, 2014).

Overall, jatropha projects have not yet shown satisfactory progress to give full confidence in other countries. Some of the projects still exist but have ended up with supplying non-energy products. The main problems were too low and uncertain productivity, and inadequacy of the oil feedstock quality to meet the specifications of the liquid fuel produced by existing technology.

An important lesson can be drawn from this experience in that it is necessary for the policymakers to assess sufficiently any technologies before making any decisions about the investment feasibility, instead of accepting an instant idea (Afiff, 2014). In the future, before any execution in Indonesia, the Ministry of Energy and Mineral Resources (MEMR) as the focal point of any energy-related programmes, should have officially approved any national programme for providing liquid biofuel feedstock.

As utilization of marginal land can take several years, the time taken to progress the land development becomes crucial, and optimization is a big challenge. An assessment of the impact of the time taken for land development can be carried out using a computer simulation (Chapters 3 and 7). Other challenges include good feedstock management (Section 4.4.3.8) especially the commitment to using the crop for energy purposes. To address the challenges, supporting policies and measures are required such as for (i) land preparation, particularly for infrastructure, landowners' understanding, land certification, local government coordination; (ii) oil feedstock productivity, and (iii) control of biofuel feedstock price.

4.6.4 Pongamia research for biofuel production in Australia

Pongamia research in Australia is among the most advanced in the world. Besides the success that has been achieved (Section 4.4.3), there were challenges in the commercialisation that have not been fully resolved. The main challenge is how to have and maintain a high oil yield given that seed productivity was highly variable across sites.

The study on pongamia in Australia pointed out that the opportunities and risks in pongamia commercialization are determined by the interaction of biological, environmental and socioeconomic factors. Doing a new project normally has a risk of investment uncertainties such as in land tenure and acquisition, limitation in clearing lands, the unclarified status of R&D regarding soil condition and productivity, the existence of attractive carbon market, and government supports based on the project's potential benefits (Murphy et al., 2012).

4.7 Conclusion

Using marginal land for energy crops can have significantly positive impacts on the economy, society, and the environment. However, before using marginal land, it is important to consider land suitability and availability, and choice of crop.

Determination of whether the land is marginal is determined by the feasibility of using it for the cultivation of a specific crop. In Indonesia, after quantifying and classifying land using a scientific method by a government body (MOF, 2013b), around 25 Mha of marginal land (classified as critical and very critical) was prioritized for rehabilitation in 2013 (MOF, 2015). Before determining an area for cultivation, a further assessment of marginal land availability for bioenergy at a local scale should be undertaken.

Unless the cause of degradation is either water or wind erosion, it is generally reversible although with a high cost. The yields of crops grown on marginal land are influenced by the type and cause of land degradation and the land restoration technique applied, being more effective from a good understanding. Crop yields can be improved through land management, water availability, and technology improvements. Crop productivity can also be increased by improving seed quality and management practices.

It is crucial to determine the most appropriate plantation crop to suit the marginal land because the time elapsed during the land development and the crop growth take several years, and the crop properties will affect the success of the project. *Pongamia pinnata* (pongamia) was chosen by this study as a suitable energy crop for marginal land use in Indonesia, based on criteria that the crop grows naturally in Indonesia, produces non-edible oil, has promising oil productivity, fixes nitrogen, produces fuelwood as a by-product, has added value from other non-oil by-products, allows short rotation cycle, and can withstand a saline environment. There is also good data, based on existing research programmes, that is useful to develop an assessment model (Chapter 7). In the real world, the decision on crop type should be up to the investor based on the evidence that is sufficient for an investment decision.

Main problems in marginal land use for energy crop include low oil yield, availability and consistency of quality seeds, and land dedication (area, location, ownership, and development) for energy crop. Lessons can be learned from past experiences in several countries to minimize risk in the project.

- Success in pongamia commercialization is determined by the interaction of biological, environmental and socioeconomic factors.
- Before making investment decisions, government bodies should be in agreement after completing a sufficient assessment.
- The owners of land and feedstock resources should commit to prioritize the crop production for bioenergy purpose.
- Innovative business is crucial for the long-term development of a country. Therefore, government support is crucial for growth in land development, increasing oil yields, and improving seed quality.

CHAPTER 5

CONVERSION TECHNOLOGY OPTIONS FOR LIQUID BIOFUEL PRODUCTION

5.1 Introduction

This chapter analyses technologies for liquid biofuel production from oil-bearing crop feedstocks grown on marginal land that are likely to become available in the future. The appropriate technology type is proposed taking account of analysis regarding the situation of liquid fuel supply and demand (Chapter 2) and strategic choice of a crop (Chapter 4). This chapter provides inputs required to develop a model for assessing bioenergy production particularly related to cost estimations and energy quantification (Chapter 7).

The rationale for choosing appropriate conversion technology is outlined in Section 5.2. Section 5.3 describes potential technological routes for drop-in biofuel production and Section 5.4 analyses and proposes appropriate technologies for the crop *Pongamia pinnata*. Section 5.5 discusses improving liquid biofuel use through technology policy.

5.2 Rationale for choosing a conversion technology type for liquid biofuel production

The availability of a suitable conversion technology plays an important role in commercial development of a biofuel system. Indonesia, a country that has a high dependence on crude oil product imports (Chapter 2), can boost its economy by maximizing the production and use of liquid biofuel. To do this more sustainably, the liquid biofuel industry should have high local content, including development of an appropriate technology.

Liquid biofuel products that are currently available in the commercial market have some limitations, especially in their utilization. Unlike crude oil products which molecules naturally consist of pure-hydrocarbon chains, existing biofuels such as biodiesel and bioethanol consist of molecules that contain oxygen which cause limitation in mixing with petroleum fuels. In order to increase the utilization of biofuels in existing liquid fuel systems, it is necessary to implement appropriate technology to give non-oxygenated biohydrocarbon or drop-in biofuel (DBF) products that have equivalent properties to petroleum fuels. The technology should also be strategically determined to maximize renewable fuel use.

"Drop-in" biofuel is defined as "liquid biohydrocarbons that are functionally equivalent to petroleum-based fuels and are fully compatible with existing petroleum infrastructure" (Karatzos, McMillan, & Saddler, 2014). Unlike oxygenated biofuels, drop-in biofuels can be mixed with either gasoline or diesel at any concentration level and therefore require no modifications to the production, storage, distribution or end-use facilities. To maximize renewable fuel utilization, the use of biofuels for land transport is the most important in the short term, though aviation fuels will also be sought in future.

5.3 Potential technological routes for drop-in biofuel (DBF) production

Potential technological routes to produce DBF using oil-bearing crops can be categorized based on feedstock type, consisting of lignocellulosic biomass and oleochemical. In the conversion process, the molecules in a feedstock are decomposed under a relatively high temperature, called thermolysis. The technology for lignocellulosic feedstock is called thermochemical routes or lignocellulosic thermolysis, while the technology for vegetable oil feedstock is called oleochemical thermolysis.

5.3.1 Lignocellulosic thermolysis

The main types of this process comprise of either pyrolysis or gasification to convert lignocellulosic biomass into bio-oil, a liquid product that contains biohydrocarbon. The main steps in the process are hydrogenation for oxygen removal and hydrocracking. The yield of liquid biohydrocarbon is influenced by the cellulose, hemicellulose, lignin composition of the biomass, the temperature and the holding time. The higher the temperature, the lower the residence time and the greater liquid biohydrocarbon yield.

The main advantage of thermolysis is the wide availability of low-cost feedstocks. However, the feedstock has very low H/C ratio compared to the H/C ratio needed for drop-in fuels (Karatzos et al., 2014). Therefore, the supply of sustainable and low-cost hydrogen to improve the ratio is a challenge. Furthermore, pyrolysis bio-oil can be unstable, corrosive, alkaline and contain solids and high moisture concentrations with increasing viscosity over time due to char catalytic actions (Jahirul, Rasul, Chowdhury, and Ashwath (2012); Cornelissen, Yperman, Reggers, Schreurs, and Carleer (2008)). Moreover, the technology is only economic at large scales (Table 5.1).

5.3.1.1 Pyrolysis

Pyrolysis is a thermal decomposition of material in the absence of oxygen or oxidative agents. For liquid biofuel production, it consists of either direct, fast, pyrolysis or indirect hydrothermal liquefaction.

- Fast pyrolysis is usually run without a catalyst (Jahirul et al. (2012); Wang (2011)). Benefits include some commercial experience that enables it to utilise process equipment at the industrial scale. However, the process temperature is high and the bio-oil usually has a low heating value, high oxygen content (Wang, 2011), and excessive water content (Karatzos et al., 2014).
- Hydrothermal liquefaction is a catalytic process that involves condensation or polymerization of the reaction intermediates (Nazari, Yuan, Souzanchi, Ray, & Xu, 2015). The advantages are that it can use wet biomass and can be co-utilized with other biofuel production technologies. Challenges in hydrothermal liquefaction include the high process pressure, the use of a suitable catalyst, and the high viscosity of the bio-oil produced. More importantly, there is still a lack of knowledge on the reaction mechanisms as the development status is still at an early stage (Karatzos et al., 2014).

Each of the processes produces bio-oil that has many qualitative similarities and many quantitative differences, one to another. Bio-oil contains oxygenated components such as phenolic compounds, alcohols, ketones and aldehydes, that will need upgrading to meet DBF specifications. The upgrading process removes oxygen, nitrogen, and water, mainly through hydro-processing. Without upgrading, bio-oil can be used directly for stationary engines used for heat/power generation that requires engine modification such as in the bio-oil storage and feeding systems (Karatzos et al., 2014).

5.3.1.2 Gasification

Gasification is the most significant step in DBF production from lignocellulosic biomass. It produces synthesis gas (syngas of mainly CO and H_2) that can be processed further through Fischer-Tropsch (FT) catalytic synthesis to produce wax and olefins at a different temperature, which are then further hydro-processed to produce FT diesel and FT gasoline. Some advantages of gasification are the short residence time and the capability to produce high-octane gasoline. Also, FT technology that uses fossil resources has been available at commercial scale such as by Sasol company in South Africa that uses coal to produce 160,000 bbl/day of fuels and chemicals, which can provide lessons learned for accelerating the biomass-based process development. However, the low selectivity of FT synthesis, the formation of tar which is difficult to handle, and the high cost of investment, operation and maintenance due to high process temperature and pressure are constraints (Karatzos et al. (2014); Rojas and Ojeda (2010); Wang (2011)). Currently, biomass gasification has been applied for generating electricity and heat at several pilot projects in several countries including Indonesia. The successful examples include Güssing Plant in Austria which produces 2 MW of electricity and 4.5 MW of heat (Guevara-Stone, 2013).

5.3.1.3 Other processes of lignocellulosic thermolysis

Other technology routes of lignocellulosic thermolysis are under earlier stage of development. For example, delignification and fractionation routes, which each involves hydrolysis and hydrogenation steps.

5.3.2 Oleochemical thermolysis

5.3.2.1 Overview of oleochemical thermolysis

Oleochemical thermolysis uses lipids such as vegetable oils, animal fats and algal oils, or fatty acid feedstocks, to produce a range of drop-in biofuels (DBF). Compared to cellulosic and sugar feedstocks, lipid feedstocks have the closest structure to DBFs as they have lower oxygen content and a higher hydrogen-to-carbon ratio. Oleochemical technology routes are currently the largest supplier of DBF (Karatzos et al., 2014).

The technology has some challenges such as the availability, sustainability, and cost of the vegetable oil feedstock. However, compared to lignocellulosic thermolysis, it is a well-developed and maturing technology with a mild process condition, lower technological risks, and less capital costs.

5.3.2.2 Feedstock suitability for oleochemical thermolysis

The composition of the DBF product is influenced by the feedstock properties, such as iodine value (IV) and carbon chain length and shape.

The IV indicates unsaturated fatty acid content in the oil feedstock that a higher IV will require the addition of more iodine to saturate double bonds. Oil feedstock that has an IV more than 100 is more suitable for biogasoline production because it supports the formation of ring shape such as isooctane to yield high octane hydrocarbons. On the other hand, oil that has IV less than or equal to 100 is more suitable for green diesel production because it supports keeping the hydrocarbon chain straight (Soerawidjaja, 2016b).

Carbon chain length and shape influence product composition and this determines the properties such as octane number and cetane number. For example, palmitic oil/acid has high suitability for producing green diesel (C_{15}-C_{18}) which quality is determined by cetane index that can increase by pentadecane content. Palmitic acid ($C_{16}H_{32}O_2$) can be decarboxylated to produce pentadecane ($C_{15}H_{32}$). Another example, oleic oil/acid has high suitability for producing green gasoline (C_4-C_{12}), the quality of which is determined by the octane rating that can be increased by the isooctane content. Oleic acid ($C_{18}H_{34}O_2$) can be decarboxylated to produce heptadecane ($C_{17}H_{36}$), that can further be cracked into nonene (C_9H_{18}) and octene (C_8H_{16}) by detaching the double bond between the ninth and the tenth carbon of heptadecane. Octane is then isomerized to form isooctane. (Soerawidjaja, 2018b)

Pongamia oil, the preferred feedstock as assessed in Chapter 4, has an IV of 105 g iodine/100 g KOH (Wargadalam et al., 2015) and with oleic acid as the major component. Therefore, pongamia is suitable for gasoline drop-in biofuel production. An IV around 100 is borderline for gasoline, but pongamia oil can also be used as feedstock for green diesel production, with a better performance than other oils that have more different chain characteristics (Section 5.4.2).

5.3.2.3 Hydrodeoxygenation

The hydrodeoxygenation process can be applied to vegetable oils and animal fats to produce hydrocarbon-based biofuels including green jet fuel, green gasoline, and green diesel. The process removes oxygen from the glyceride molecules in the feedstock through hydrogenation and deoxygenation. Hydrogenation consists of saturation of triglyceride molecules, followed by the formation of carboxylic acids. Then, the saturated carboxylic acids are deoxygenated through parallel reactions consisting of further hydrogenation and decarboxylation. The choice of catalyst determines the product composition (Karatzos et al. (2014); Liu, Sotelo-Boyás, Murata, Minow, and Sakanishi (2012); Sari (2013)).

One of the advantages of this process is its availability at commercial-scale that has supplied the most significant share of drop-in biofuel supply with 3.6 Gl/yr production capacity in 2016. Neste Oil, the largest producer to date, increased its production capacity from 2.4 Gl in 2013 to 3.3 Gl/yr in 2017 (Karatzos et al. (2014); REN21

(2017)) The other benefit is the possibility of co-processing vegetable oil feedstock and crude oil in existing oil refineries. Some challenges in implementing this process include the availability, sustainability, and cost of the vegetable oil feedstock and the supply of sustainable and low-cost hydrogen.

5.3.2.4 Metal soap decarboxylation

This process converts feedstock in the form of fatty acids into DBF (jet fuel, gasoline or diesel) through decarboxylation or catalytic pyrolysis (distillation) of metal soaps. The metal soap is formed through saponification of fatty acids on the catalyst in the form of oxide/hydroxide of alkaline earth or transition metals. (Neonufa, Soerawidjaja, & Prakoso, 2017)

Decarboxylation process results in biohydrocarbons that keep the chain structure straight as in the feedstock. As the straight chain is also the characteristic of diesel fuel hydrocarbons, this process is suitable for green diesel production. On the other hand, the isomerization process results in aromatic biohydrocarbons that have a cyclic structure, and hence this process is appropriate for green gasoline production.

5.3.3 Combined thermolysis and biological

This is the least discussed technology. An example is the fermentation of synthesis gas and catalytic reforming of sugars/carbohydrates to produce alcohols (Karatzos et al., 2014). Advantages of this combined process are the use of feedstock carbon, less risks, and fast process. However, some challenges face the technology development such as catalyst suitability, low yield, high feedstock cost, and hydrogen requirement.

5.4 Choosing a DBF technology

5.4.1 Criteria for choosing an appropriate DBF technology

To determine the most suitable type of technology for DBF production in Indonesia, several characteristics should be considered, such as:

- availability of feedstock and raw materials (including hydrogen);
- local-content at commercial production, including technological expertise to support the sustainability of the technology implementation;
- economic feasibility for small scale production that is important for the implementation over many small islands, and

- stage of development and expected progress to assess the time of the technology becoming available at the commercial scale (green gasoline is expected to be available sooner than cellulosic ethanol from pongamia wood).

Table 5.1 shows a comparison of potential technologies for DBF production using feedstocks from an oil-bearing crop such as pongamia. The parameters consist of the feedstock type, the conversion technology, the products, the liquid biofuel yield, the reaction temperature and pressure, the economic scale of production that has been assessed, the estimated upgrading cost, the local content issues, and the development state.

Data and information in the table were collected through different methods. For technologies that use lignocellulosic biomass feedstock, data were taken from literature which has been widely discussed both at a global and national scale. However, the literature on technology for oil/fat feedstocks is less available, especially for metal soap decarboxylation. Therefore, the data and information regarding this technology were collected through a focus group (Appendix D) and personal communications (Appendix H).

Table 5.1. Potential technology routes for drop-in biofuel production from a range of biomass feedstocks

No.	Conversion technology route	Feedstock	Products	Yield of biofuel (% per volume of feedstock)	Temperature (°C)	Pressure (bar)	Development status/issues	Feasible economic scale assessed (Ml/yr)	Conversion cost ($/l)	Local content issues	References
A	**Lignocellulosic thermolysis**										
A1	Fast pyrolysis	Lignocellulosic biomass	Bio-oil (oxygenated component); Direct use for stationery heat/power generation; Needs upgrading for use as DBF.	Up to 75% bio-oil; Up to 33% DBF	600-1000	<5	Bio-oil: Commercial; DBF: Demonstration	>=20,000	Fast pyrolysis:Cost $180/t bio-oil; $0.9/l DBF for 100,000 Ml/yr fast pyrolysis.	Technological mastery	Karatzos et al. (2014); Maschio, Koufopano, and Lucchesi (1992); Bridgwater (2012); Behrendt, Neubauer, Oevermann, Wilmes, and Zobel (2008); Demirbas (2000a) Demirbas (2000b)
A2	Hydrothermal liquefaction	Lignocellulosic biomass	Bio-oil (oxygenated component); Direct use for stationery heat/power generation; Needs upgrading for use as DBF.	up to 70% bio-oil	250-550	50-250	Pilot-industrial scale			Hydrogen, catalyst, technological mastery	Karatzos et al. (2014); Dimitriadis and Bezergianni (2017); Gollakotaa, Kishoreb, and Gu (2018); Demirbas (2000a)

No.	Conversion technology route	Feedstock	Products	Yield of biofuel (% per volume of feedstock)	Temperature (°C)	Pressure (bar)	Development status/issues	Feasible economic scale assessed (Ml/yr)	Conversion cost ($/l)	Local content issues	References
A3	Gasification + Fischer Tropsch + Hydroprocessing	Lignocellulosic biomass	Bio-FT (diesel / gasoline)				Demonstration			Hydrogen, technological mastery	
	Gasification	Dry lignocellulosic biomass	syngas	85% syngas / feedstock	800-1000	1-50					Karatzos et al. (2014); Molino, Larocca, Chianese, and Musmarra (2018)
	Fischer Tropsch (FT) of syngas		FT wax / olefins		Up to 350	Up to 30					Karatzos et al. (2014)
	Hydroprocessing of FT wax/olefins		Bio-FT (diesel / gasoline)		Up to 400	Up to 150					Karatzos et al. (2014)
B	**Oleochemical thermolysis**										
B1	Hydrodeoxygenation	vegetable oil/fatty acids	Biohydrocarbons (diesel, gasoline, jet fuels)	Theoretical: 76% liquid hydrocarbons from palm oil; Pilot-scale at ITB Indonesia, July 2018: yield 45-53% liquid hydrocarbons; feedstock = refined palm oil	General:300-400; ITB:450-550	General: 30-60; ITB: Atmospheric.	Early commercial	>100,000		Hydrogen	Karatzos et al. (2014); Subagjo (2018b);; Pearlson, Wollersheim, and Hileman (2013)

No.	Conversion technology route	Feedstock	Products	Yield of biofuel (% per volume of feedstock)	Temperature (°C)	Pressure (bar)	Development status/issues	Feasible economic scale assessed (Ml/yr)	Conversion cost ($/l)	Local content issues	References
B2	Saponification + decarboxylation	vegetable oil/fatty acids	Biohydrocarbons (diesel)	Theoretical: 76% liquid hydrocarbons from palm oil; Pilot scale R&D at ITB Indonesia 2017: yield 62% liquid hydrocarbons; feedstock=palm stearin.	Saponification using hot ethanol before boiling; Decarboxylation: 250-375.	Atmospheric	R&D Pilot scale	>=50,000		No issues if all production equipment is local	Soerawidjaja (2018c); Neonufa et al. (2017); Kaisha (1923)
B3	Saponification + pyrolysis (dry distillation)	vegetable oil/fatty acids	Biohydrocarbons (gasoline)	76% liquid hydrocarbons from palm oil (theoretical); 25% gasoline in 1947 in China; The qualitative test shows all liquid products is a hydrocarbon (2017 Lab scale R&D at ITB Indonesia).	Saponification using hot ethanol; Pyrolysis: 350-550	Atmospheric	R&D Lab small scale	>=50,000			Soerawidjaja (2018c); Karatzos et al. (2014); Neonufa et al. (2017); Chia and Shen (1947)
C	**Combined thermolysis and biological**										
C1	Gasification + Biological	Lignocellulosic biomass	Biohydrocarbons via alcohols				R&D			Hydrogen, catalyst, technological mastery	(Karatzos et al., 2014)

Note: empty cells = no data

5.4.2 Options for appropriate DBF technology in Indonesia

Based on overall criteria in the previous section and the properties comparison in Table 5.1, the preferable technology for DBF production using oil-bearing crops in Indonesia is oleochemical thermolysis, consisting of hydrodeoxygenation of vegetable oil, metal soap decarboxylation, and metal soap pyrolysis.

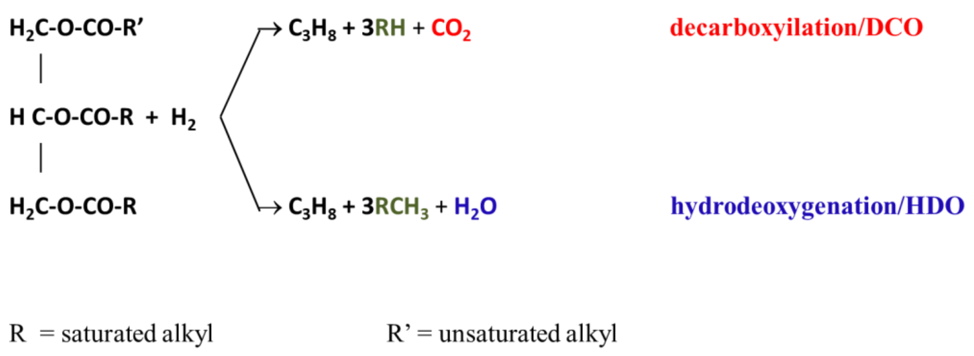
The oleochemical thermolysis technologies were initiated overseas and have been in the development process for several years at Institut Teknologi Bandung (ITB), a tertiary education institution in Indonesia. The liquid biohydrocarbon products have been tested and proven for their equivalence to petroleum products. However, the production rate is still insufficient for testing the fuels in a full road test on a range of vehicles. The development is continuing to improve the desired product yield as well as the process efficiency.

5.4.2.1 Development of hydrodeoxygenation technology

Research and development of a hydrodeoxygenation process that has been commercialized in some other countries (Section 5.3.2.3) keep continued which aims to increase efficiency and thus decreases production cost at the local level.

The hydrodeoxygenation process is versatile given it can produce “green” fuel equivalents of diesel, gasoline, or jet fuel by selecting a suitable catalyst. This technology which has been commercialized in some countries (Section 5.3.2.3), has been developed in Indonesia for several years, especially in developing the suitable catalysts and improving the process efficiency to reduce upgrading cost at small-scale production levels.

The reaction mechanism of the hydrodeoxygenation process is shown in Equation 5.1. In the hydrodeoxygenation step, triglycerides, the dominant component of vegetable oils, are saturated followed by formation of carboxylic acids (fatty acids). Then the carboxylic acids are deoxygenated through four parallel reactions.



Equation 5.1 Reaction mechanism of hydrodeoxygenation (Subagjo, 2018a)

Fig. 5.1 shows a simplified flow diagram of the hydrodeoxygenation process for hydrotreated vegetable oil (HVO, a DBF) production from vegetable oils/animal fats. In improving the process efficiency and increasing the output of desired products, the process at ITB is improved by applying Houdry fixed-bed catalytic cracking technology (Hook, 1996). It was invented by Eugene Jules Houdry to convert crude petroleum into higher shares of gasoline with higher octane rating in an efficient way through a catalytic conversion.

Currently, the main feedstock is vegetable oil, such as palm oil, which is readily available in the market. The theoretical biofuel yield is 76% of total input oil volume, although the pilot-scale yield at ITB has achieved only 45-53% liquid hydrocarbons (July 2018), using palm oil feedstock and aluminosilicate-based catalyst (Subagjo, 2018b).

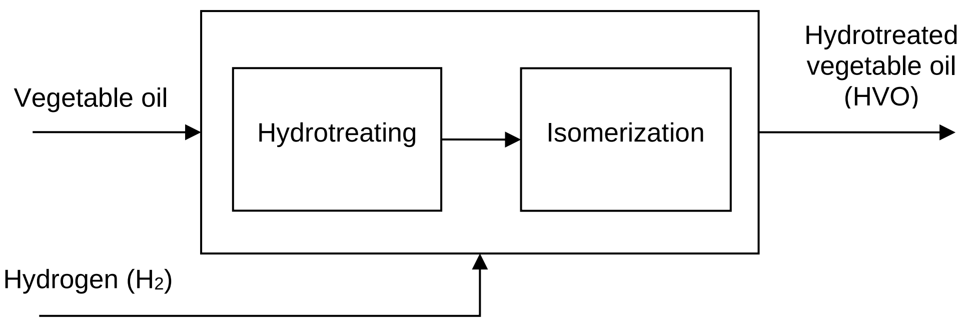


Fig. 5.1 Simplified flowchart of hydrodeoxygenation process to produce hydrotreated vegetable oil (HVO) from vegetable oils (Neste, 2016).

The laboratory scale production facility and DBF samples from the Houdry process at ITB Indonesia are shown in Figs. 5.2 to 5.5.

A green diesel sample was tested, and the characteristics were compared to fatty acid methyl esters (FAME). The green diesel was higher than FAME in cetane number, oxidation stability, low temperature efficiency, and stability, and similar in sulphur content, gaseous emission efficiency, and CO_2 emission. (Subagjo, 2018a)

Production capacity of green gasoline using this technology at ITB laboratory is currently 10 l/day. In November 2018, co-processing for green gasoline and green diesel production trials at 12 Ml/batch were successfully carried out in oil refineries of PT Pertamina, the state-owned oil and gas company (DGNREEC, 2018). This trial has proved the DBF technical feasibility at commercial scale.

Fig. 5.2. Laboratory scale production of green diesel from vegetable oil at ITB (12th May 2017).

Fig. 5.3 Refined palm oil feedstock (left), catalyst (centre), and green diesel liquid biohydrocarbon production through hydrodeoxygenation (right) (T=450-550ºC; atmospheric pressure; liquid biohydrocarbon yield=45-53%). (ITB laboratory, 12th May 2017)

Fig. 5.4 Laboratory scale production of green gasoline from vegetable oil through hydrodeoxygenation (ITB laboratory, 12th May 2017)

Fig. 5.5 Feedstock (left), catalyst (middle left), and green gasoline products before & after distillation (middle right and right) through hydrodeoxygenation of refined palm oil (T=450-550°C; atmospheric pressure; liquid biohydrocarbon yield=45-53%;). (ITB laboratory, 12th May 2017)

Development of green jet fuel using hydrodeoxygenation technology at ITB has been conducted in cooperation with PT Pertamina since 2010. The production capacity is currently 3.6 l/day using coconut oil feedstock, which product has freezing point (-67)°C which is far better than the standard specification for jet fuel (-47)°C (Fig. 5.6).

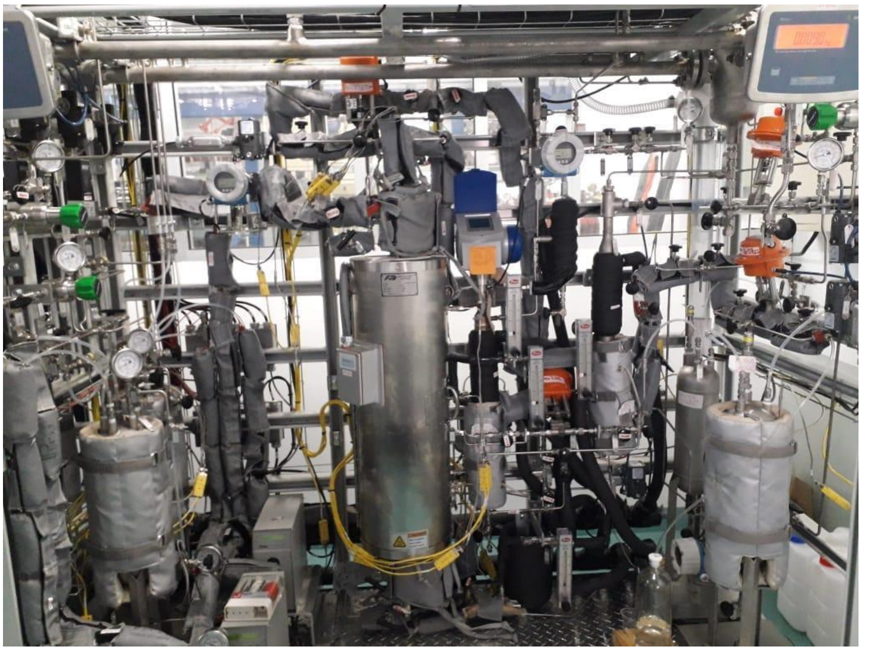


Fig. 5.6 Laboratory-scale production of green jet fuel from vegetable oil through hydrodeoxygenation at ITB Laboratory (Subagjo, 2018a)

It is expected that the hydrodeoxygenation process for DBF production using the Houdry process could reach the commercial scale by 2023 (DBF-TechnologyGroup, 2016).

5.4.2.2 Development of metal soap decarboxylation technology

The research and development for the metal soap decarboxylation was initiated in the 1920s but stopped after the Second World War due to the production cost becoming infeasible (Soerawidjaja, 2016a). This technology development was started in 2015 by the biofuel technology group at ITB to improve process efficiency and get a higher yield of DBF products.

Generally, a fatty acid is a chain of hydrocarbon ended by a carboxyl group (-COOH). The decarboxylation process starts with the formation of metal (M) soaps from fatty acids, using a catalyst from alkaline metal with two valence electrons (Equation 5.2). The metal soap is then heated to remove the carboxyl group and leave a hydrocarbon, similar to the structure of petroleum-based fuels. Soap decarboxylation usually happens in the absence of oxygen or oxidative agents at 250 – 375 ºC and low pressure (Markley (1961); Ralston (1948)).

$$M(OH)(OOCR) \longrightarrow MCO_3 + RH \qquad \text{(Equation 5.2)}$$

The process can be run without the addition of hydrogen when a fatty acid is used as feedstock. When the feedstock is a natural oil, before being fed into decarboxylation, the glycerides are first converted into fatty acids via lipolysis using acetone powder.

Currently, the research being undertaken at ITB is for green diesel production (Neonufa et al., 2017). The main feedstock is palm stearin, a palm oil fraction that consists of around 50% palmitic acid and 35% oleic acid. Other feedstocks that have been tried include pongamia oil (Chapter 4). The metal soap is produced using basic metal with two valence electrons (Fig. 5.7). Experiments have been carried out to find optimum conditions and the most suitable catalyst. Catalysts that have given the best results include Mg-Zn and Mg-Fe.

In the first step of the process, palm stearin is saponified at 60^{o}C using hot ethanol to form Na-basic soaps. Then, MgZn solution to form $(M_{mix})^+$ basic soaps. Afterwards, the solution is purified, dried, and then decarboxylated at 350^{o}C and atmospheric pressure. The liquid product is then fractionated to separate green diesel from any by-products. The yield of liquid biohydrocarbon is 62%. The theoretical yield is 70% for oleic soap, and lower for non-oleic or more saturated soaps due to more production of gaseous products (Soerawidjaja, 2018c).

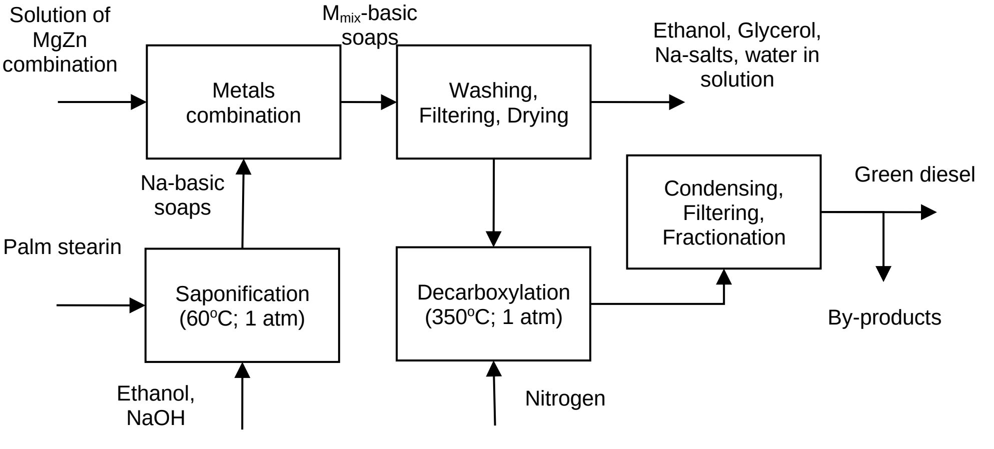


Fig. 5.7 Flow diagram of metal soap decarboxylation process to produce green diesel from palm stearin (Neonufa et al., 2017)

The production can be implemented commercially at a small scale. As the technology is such that component manufacturing, plant assembly and production and plant operation are within the capability of the local available workforce, technology sustainability at the nation-wide level will improve.

The laboratory scale production facility and pictures of DBF samples at ITB Indonesia are shown in Fig. 5.7 and Fig. 5.9.

Fig. 5.8. Reactors for liquid biohydrocarbon production from fatty acid: (i) green diesel production through metal soap decarboxylation and (ii) green gasoline production through metal soap pyrolysis (ITB Indonesia, 2015, picture by ITB)

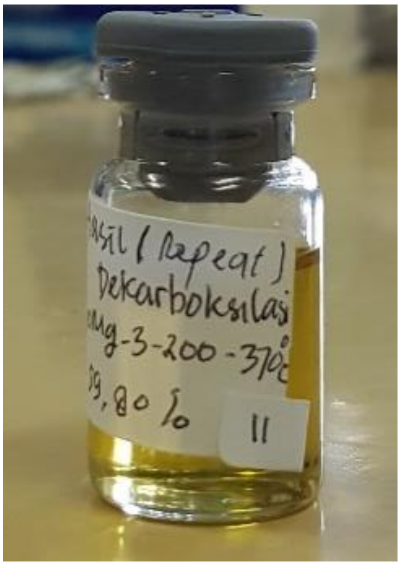


Fig. 5.9 A sample of liquid biohydrocarbon produced from decarboxylation of metal soap (T=370^{o}C; P=atmospheric; yield=59.80%; feedstock: palm stearin). (ITB, 12th May 2017)

The scaling up of production through this process is likely not to affect DBF production cost significantly due to the process simplicity can be equalized to transesterification technology (Soerawidjaja, 2016a). It is expected that the decarboxylation process for DBF production is expected to be available at commercial scale by the year 2023 (Soerawidjaja, 2018d).

5.4.2.3 Development of metal soap pyrolysis (dry distillation)

As for decarboxylation (5.4.2.2), this technology development also began in 2015 by the biofuel technology group at ITB using the same equipment (Fig. 5.8) to improve the process efficiency and get a higher yield of DBF products.

Both processes start with saponification but metal soap pyrolysis is usually performed at a higher temperature of 400 ^{o}C or above, at which the ring structure that determines high octane rating is formed. The reaction of metal soap pyrolysis is shown in Equation 5.3.

$$\text{Metal soap} \longrightarrow \text{green gasoline + green diesel} + H_2O + CO_2 \qquad \text{(Equation 5.3)}$$

Various biomass feedstocks have been tried including pongamia oil and *Reutealis trisperma* oil with the pyrolysis performed at 450-550 ^{o}C and atmospheric pressure. The catalysts tried were a variation of Mg, Zn, Fe, and Cr metals (Fig.5.10) with the resulting products consisting of paraffin, olefin, aromatic and cyclic molecules. For Reutealis oil, the acid value decreased from 3.37 mg KOH/g feedstock to 0.37 mg KOH/g liquid product, which indicated that the products consist only of hydrocarbon (Soerawidjaja, 2015). The research was a development of past research in China in 1947 where the pyrolysis took place at 350-550 ^{o}C and yield was 70-80% liquid products including 25% green gasoline (Kaisha, 1923).

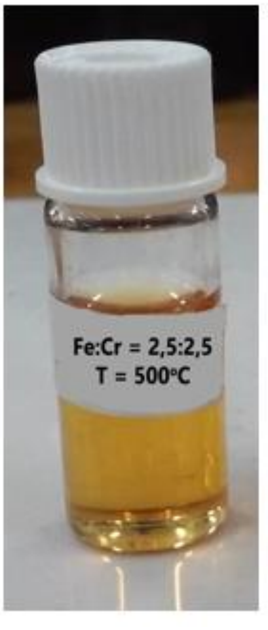


Fig. 5.10 Sample of liquid products of metal soap pyrolysis from Reutealis oil (ITB, 2015)

As in the metal soap decarboxylation technology, the scaling up is likely insignificantly to affect upgrading cost as the process complexity was assessed equal to biomass gasification technology (Soerawidjaja, 2016a). DBF production through this process is expected to become available at commercial scale by the year 2023 (Soerawidjaja, 2018d).

5.4.2.4 Choice of DBF technology by fuel type

The three processes of hydrodeoxygenation, metal soap decarboxylation, and metal soap pyrolysis (Sections 5.4.2.1 to 5.4.2.3 and Table 5.1), are similar in process complexity level, production cost, and the estimated year of commercial readiness. On the other hand, hydrodeoxygenation requires hydrogen inputs whereas metal soap decarboxylation, and pyrolysis does not, especially when the feedstock is fatty acids.

Based on the desired characteristics (Section 5.4.2), the effect of feedstock properties (Section 5.3.2), and the progress in technical knowledge, options for DBF production from *Pongamia pinnata* (Chapter 4) both diesel and gasoline blends with DBF can be achieved.

a) Green diesel

   The preference is metal soap decarboxylation that minimizes any risk and cost of hydrogen supply. Where hydrogen supply is not a problem, hydrodeoxygenation is an option to meet high DBF demand due to shorter preparation time.

b) Green gasoline

   Metal soap pyrolysis is preferable since hydrogen can be absent. As for green diesel, where hydrogen is produced with low carbon emissions, cheap and readily available, hydrodeoxygenation is another option that can help meet high DBF demand.

c) Green jet fuel

   Production of this green fuel is expected to use hydrodeoxygenation technology, as shown by the existing positive progress.

5.5 Improving liquid biofuel use through technology policy

As technology development and investment affects to one another (Avianto & Tasrif, 2007), development of the most appropriate technology for liquid biofuel production in Indonesia plays crucial role in improving long-term economic growth through reducing oil fuels import. An appropriate technology should support sustainability, therefore, maximizing the local content is very important.

Energy-technology innovation (ETI) is the set of activities in creating or improving energy technologies that can increase energy resources and energy services qualities; and lower costs of environment, economy and politics incurred by the energy supply and use. ETI characteristics comprises stages of research, development, demonstration, and deployment (RD3) and the existence of feedback loops between different phases. (Gallagher, Holdren, & Sagar, 2006).

ETI is vital to overcome the energy challenges which are time-sensitive in terms of the economic, environmental and international security, those are regarding the growing demand of energy and the tend to the low-carbon economy. It is crucial to minimize delay in actions to avoid more of costs to the low-carbon economy. (Anadon & Holdren, 2008).

Funding an ETI that has high cost usually generate a conflict between the short-term costs to pay and the long-term benefits, that incorporates political sustainability (Section 2.5.3). In the process of allocating the annual state budget to fund an ETI, it is necessary to assess continually the impact of the technical performance to the national policy and vice versa (Broniatowski & Weigel, 2004). To help with trade present cost against future cost, some important factors in the technology-policy feedback loop should be concerned. For instance, translating long-term considerations of system design into short-term, frequently-delivered benefits for the system's stakeholders; and the communication between the representatives of the President and members of the Congress (Broniatowski & Weigel, 2004).

The investment in the early stage of technology development is very dependent on the government. In Indonesia, one of the investment sources for liquid biofuel development is the fund collected from palm oil export fee. The palm oil export fee that has been implemented since 2015 can be used for supporting palm oil sustainability that includes enhancing the downstream industry though research and development activities based on the Presidential Regulation 61/2015. Palm oil is current biodiesel feedstock and will be the major feedstock in the early implementation of the advanced technology, that can also be applied to other feedstocks such as from marginal land.

5.6 Model inputs

DBF in the model generally represent all liquid fuels. In liquid biofuel transition sub-model which shows the transition from oxygenated biofuel to drop-in biofuel, the oxygenated biofuel is represented by palm biodiesel due to it has been the only liquid biofuel that exists in the market.

The decarboxylation process was chosen to provide parameter values for input into the system dynamics model in Chapter 7. The inputs consist of conversion efficiency, plant size, upgrading costs and the expected time for technology readiness for commercialization.

- Conversion efficiency

  The conversion efficiency was assumed to be 76% DBF from the oil feedstock (Table 5.1).

- Plant size

  The smallest plant size that is expected to be economically feasible is 50 Ml/yr so that scale has been used in the model (Table 5.1).

- Upgrading cost

  A techno-economic analysis for DBF production via metal soap decarboxylation is not yet available. Therefore, an estimation of the upgrading cost was taken from a techno-economic analysis of the most similar economic feasibility, that is bio-jet fuel production via hydrodeoxygenation process (Pearlson et al., 2013). This analysis showed that the upgrading cost for green diesel, green gasoline and bio-jet fuel are very slightly different. For the smallest production scale of 116 Ml/yr, the upgrading cost was $0.46/l of DBF that includes on-site hydrogen production of $0.10/l of DBF. (Pearlson et al., 2013). For the model in this research study, the hydrogen cost was assumed to be zero as the decarboxylation process requires no hydrogen. Therefore, the upgrading cost used for the model input was assumed to be USD 0.36/l DBF. However, the model allows for the variable hydrogen cost and can be adjusted if necessary.

  The learning effect from capacity scale on the production costs for the decarboxylation process was assumed to be insignificant due to the process difficulty at every production scale is similar (Section 5.4.2).

- Expected time for technology readiness

  The decarboxylation technologies were estimated to have similarity in economic plant size and production cost when they first become commercially feasible. The single potential issue that determines the actual year of technology readiness in the model is the continuity of R&D funding. Since 2016, the research has been funded through Grant *Riset Sawit* (Palm Research) by the Indonesian Ministry of Finance. However, this was paused in 2017 due to policy changes. Recently, the funding opportunity has been offered again for execution in 2019 (Appendix D). For the next development phases, support for running the proposed industrial demonstration-scale production plant has been tentatively shown by a private large oil palm plantation company (Appendix D).

Funding is the main factor that will affect the actual progress rate of commercial development. If from now on, successful investments in the technology are obtained, it has been assumed that the conversion technology will be commercially available by 2023 (Appendix D, H). Therefore, the time for technical technology readiness was assumed to be five years after 2018, the start time of the model simulation.

The preferable technology route is metal soap decarboxylation for green diesel, metal soap pyrolysis for green gasoline, and hydrodeoxygenation for green jet fuel. The model was simulated for metal soap decarboxylation. If in reality, metal soap decarboxylation progresses at a slower rate than expectation, the next preferable one is hydrodeoxygenation route.

After the technical readiness, it will normally take another few years for preparing the implementation of a new energy technology in the Indonesian rural area, that is around 3-5 years after a program from central government is accepted by local government. The main challenge is handling social issues that affect the stakeholders' commitment (Saparita, 2017).

5.7 Conclusions.

To increase liquid fuel self-sufficiency in Indonesia, it is crucial to use a more appropriate technology which allows a high level of co-use with petroleum fuels in existing engines, such as by using drop-in biofuels (DBF).

Important criteria in considering the preferable conversion technology for DBF production in Indonesia include the feedstock availability, indigenous technology development, the economic feasibility, and the development status.

Based on the analysis results, among the potential technology routes for DBF production using feedstock from oil-bearing crops, the preferable technology for Indonesia is metal soap decarboxylation, and the other option is hydrodeoxygenation.

CHAPTER 6
SELECTION OF THE CASE STUDY

6.1 Introduction

The island of Sumba, chosen as a case study, is described in Section 6.2. This chapter explains the reasons for choosing the island (Section 6.3), describes socioeconomic condition of selected regencies (Section 6.4), and assesses the marginal land potential for energy crop production (Section 6.5) which connects to the analysis in Chapter 4.

Section 6.6 identifies the factors that affect marginal land development for energy crop production, and these are used as variables in the model (Chapter 7). Finally, Section 6.7 lists the inputs that are provided by previous sections for the system dynamics model in Chapter 7.

6.2 Profile of Sumba

Sumba island is located at 9.6993^o S latitude and 119.9741^o E longitude, in eastern part of Indonesia. It consists of four regencies namely East Sumba, Central Sumba, West Sumba, and North West Sumba (Fig. 6.1). The population in 2013 was 828,104 distributed over around 1.1 million ha area (BPSKSTG (2014); BPSKSTM (2014); BPSKSBD (2014); BPSKSBR (2014)).

Sumba has various renewable energy potential from bioenergy heat and power, solar power, wind power, and tidal power. No geothermal resources exist. At present, petroleum oil fuel is used for transportation and power generation, which consumption rate in 2013 was around 71.8 million litres were consumed in 2013, 5% more than in 2012 (BPSKSTM, 2014). As Sumba has no crude oil resources, all liquid fuel is imported from another island. Around 42.7% of the population were connected to the electricity grid in 2015, having grown from 24.1% in 2010 (Amalo, 2016). Bioenergy contribution came from biogas and woody biomass for electricity. Bioenergy is a renewable resource that can provide electricity with a higher availability factor and higher capacity factor compared with solar or wind without costly storage.

Fig. 6.1. Location of Sumba (top); The four regions of Sumba and the main towns in each region (bottom). (GeospatialInformationAgency (2015); StatisticsIndonesia (2014); StatisticsIndonesia (2012); Winrock_International and Hivos (2010))

Sumba has a semi-arid climate with two seasons, dry and rainy, and a temperature range between 20-34°C (BPSKSTG (2014); BPSKSTM (2014); BPSKSBD (2014); BPSKSBR (2014)).. The rainy period is from January to April, while the dry months are from July or August to October. The precipitation is diverse but tends to be lower on the more eastern part. The majority of East Sumba has around 500-2,000 mm of rainfall per year, with Central Sumba higher around 2,000-2,500 mm/year (Fig. 6.2).

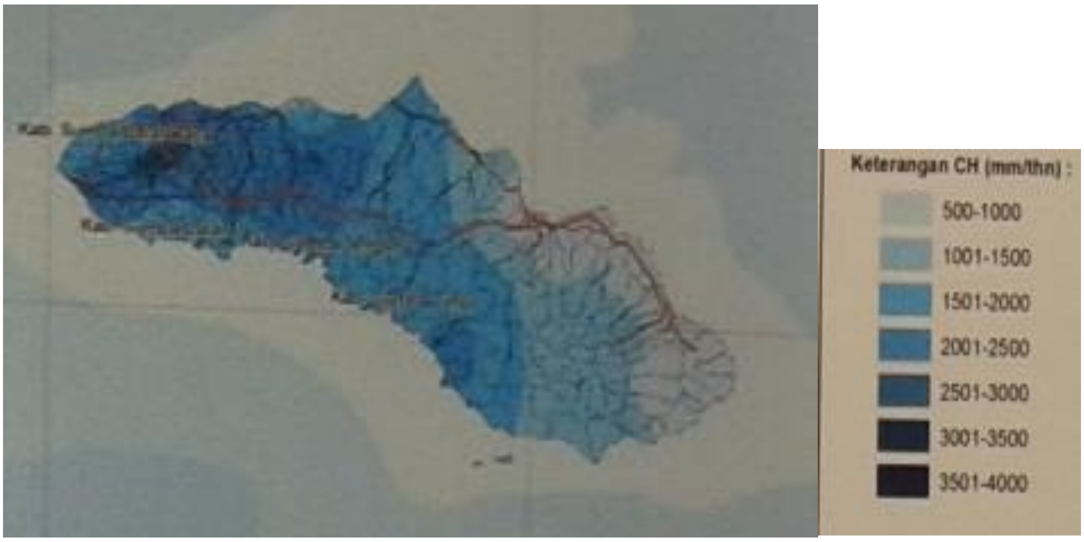


Fig. 6.2 Rainfall distribution across Sumba (UGM, 2013e)

The land includes valleys (38%), terrace (25%), and plains (16%). The land coverage is dominated by shrubs (57%) and savanna (17%) (Anonymous (2005) in Njurumana (2008a)). Half of the land area was identified as “critical” (MOF, 2015). Slopes which do not exceed 40% cover 53% of total area, with a slope over 20^{o} (44%) difficult to plough (Jarasiunas, 2016). There is no data for the land area in Sumba with slopes below 20%. The representatives of the forestry agency and the land agency in East Sumba stated that most slopes of marginal land are arable ((EastSumbaForestryAgency, 2016); (EastSumbaLandAgency, 2016)).

6.3 Reasons for choosing Sumba as a case study

Sumba was chosen due to:

- the status as an iconic island with renewable energy potential;
- no petroleum resources available for liquid fuel production (self-energy sufficiency);
- the significant existence of marginal land;
- the absence of the geothermal resources, so that biomass is the only resources for providing power with a high availability/capacity factor; and
- the easy access to Bali Island which is one of the Indonesian most strategic islands, in supporting implementation of DBF production using feedstock from marginal land.

The Indonesian Government has determined that Sumba will be energized by 100% of renewable resources because, *among other things,* it possesses good renewable energy resources which have been estimated to sufficiently meet the long-term demand (TSIID, 2012).

Sumba has a high dependence on petroleum fuel that is imported from elsewhere. Consumption of transport fuel in 2009 consisted of 19.5 Ml gasoline and 22.53 Ml diesel (Winrock_International & Hivos, 2010) also consumed to generate electricity. Sumba generates around 50 GWh on-grid electricity per year (BPSKSTG (2014); BPSKSTM (2014); BPSKSBD (2014); BPSKSBR (2014)) from mainly diesel fuel generators and hydro-power.

Based on Geological Agency data, there is no geothermal resource identified in Sumba (DGNREEC, 2014). Therefore, bioenergy could play a vital role in providing electricity with a high availability factor (around 85%) compared to other identified renewable energy resources such as solar (around 40%), hydro (around 50%) and wind (around 30%) (Soerawidjaja, 2010).

Sumba has biomass potential to produce bioelectricity and liquid biofuel. Agricultural residues could fuel a 4 MW plant (DoB, 2012). To produce liquid biofuel feedstock, currently cassava and sugarcane for bioethanol production and coconut and jatropha for biodiesel production have the most potential with available plantations (BPSKSTG (2014); BPSKSTM (2014); BPSKSBD (2014); BPSKSBR (2014)). However, cassava, sugarcane and coconut are food commodities and unsuitable for growing on marginal land. Jatropha produces an inedible oil and can grow on marginal land and was tried in a marginal land use project a few years ago that it was discontinued due to disappointing progress (CentralSumbaEnergy (2016); EastSumbaForestryAgency (2016)).

Marginal land in Sumba is significant and has potential to produce suitable energy crops. The marginal land area and characteristics in Sumba island are described in Section 6.4.

Due to time limitation in doing interviews with the landowners and policymakers, only two regencies were chosen for providing inputs to the model, namely East Sumba and Central Sumba:

- Their combined area included 80% of the critical land area on Sumba island.
- East Sumba was the only regency that can provide adequate data and information. Where relevant, some were assumed to be the same as Central Sumba.

- The adjacent locations can support the integration of design and management for a liquid biofuel project.

6.4 Socioeconomic condition of selected regencies

6.4.1 Social factors

East Sumba and Central Sumba are among Indonesian less developed regencies. Human Development Index in 2017 in these two regencies was 64.19 and 59.39 respectively, where percentage of poor people was 31.03% and 36.01% respectively. (BPSKSTM (2018); BPSKSTB (2018))

Sumba has indigenous people community who practice Marapu belief. They have customary authority exists at levels of village, district, and regency. The customary institution consists of traditional figures, society figures, and religious figures, chosen by people and confirmed by local government. Elements of customary law comprises the people, sanction, and enforcement agency.

Customary law and formal law complement each other. Investment activity is carried out with a respect to indigenous people rights and providing access of area management for Sumba people. Problems are discussed by local government and local house of representatives.

In society, ethnic (traditional) elders play an important role such as in uniting people and acting on law violation. In implementation of public programs, they are often more influential than the local government.

6.4.2 Economic factors

Sumba gross domestic regional product (GRDP) (current market price) in 2017 was IDR 11.7 trillion of which around half belonged to East Sumba and around quarter to Central Sumba (BPSKSTM (2018); BPSKSTB (2018)).

The economic growth in 2017 in East Sumba was 5.14% which main contributors were agriculture, forestry and fishery sectors. The important industries include weavings and sea salt. In Central Sumba, it was 4.92% which main sectors were agriculture, livestock, fishery, and forestry. There is an excellent tourism potential throughout the island yet mostly unexploited. (BPSKSTM (2018); BPSKSTB (2018))

6.5 Marginal land potential for energy crop

6.5.1 Marginal land characteristics

Marginal (or critical) lands occur both naturally such as stony soils, saline soils, and steep slopes, and land degradation resulting from human activities, especially forest degradation which is caused by human activities for area expansion through illegal logging and forest burning. Forest or crop residue burning is a habit by some in a dry season on land that is not their own. The motives and reasons are various, such as growing grass for feeding, supplying fuelwood, maintaining the residential area, cleaning the environment, hunting, pasturing, and being jealous of others who have land. Possessing livestock is important for social status among Sumba people.

People keep burning the land because they lack understanding about the negative impacts on the quality of soil, plantation and water that are interrelated. They also lack knowledge in alternative agriculture techniques on dry land and the available government support. The causes have increased the destructing activity which in turn keep the people in poverty (Njurumana (2008b); (CentralSumbaRegency, 2016)).

The area of marginal land is decreasing in line with the rehabilitation program through the Ministerial Decree of Forestry Nom SK. 781/Menhut-II/2012 concerning Establishment of Map and Data of Forest and Critical Land. Based on the Governmental Regulation No. 76 year 2008 verse 8 concerning Forest Rehabilitation and Reclamation, the rehabilitation is applied to all forests and critical lands. Then, in preparing a planning for forest and land rehabilitation, map and data of forest and the critical land of the year 2011 was established. In 2013, the map was revised due to significant progress in land rehabilitation. The critical land areas in 2011 and 2013 are shown in Fig. 6.3.

Critical land area in East Sumba consists of 125,000 ha inside the forestry area and 250,000 ha outside the forestry area. The land in forestry area is officially owned by the central government that is established through a ministerial decree. Central Sumba has 100,000 ha critical land. The critical area that has been cultivated in East Sumba is around 10% (EastSumbaLandAgency, 2016). Fig. 6.4 shows the distribution of critical land in East Sumba and Central Sumba in 2013.

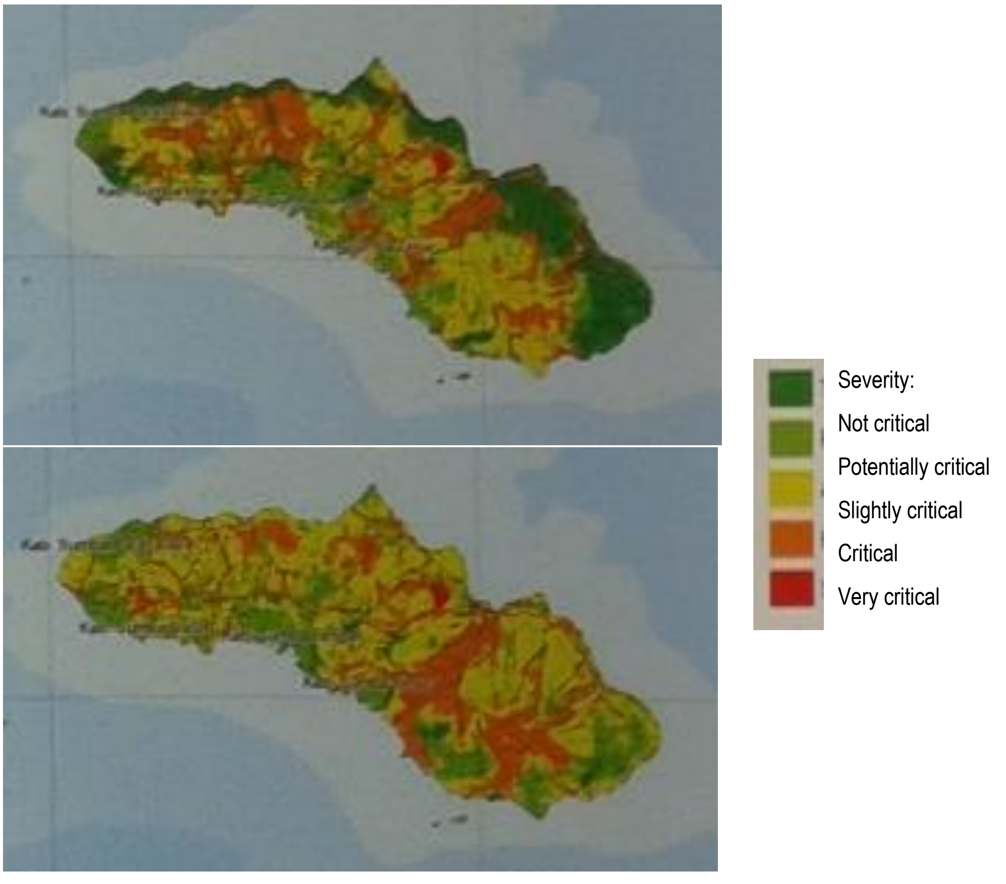


Fig. 6.3 Distribution of critical land in Sumba island in 2011 (left) and 2013 (right) after revision (UGM, 2013a) and (UGM, 2013b)

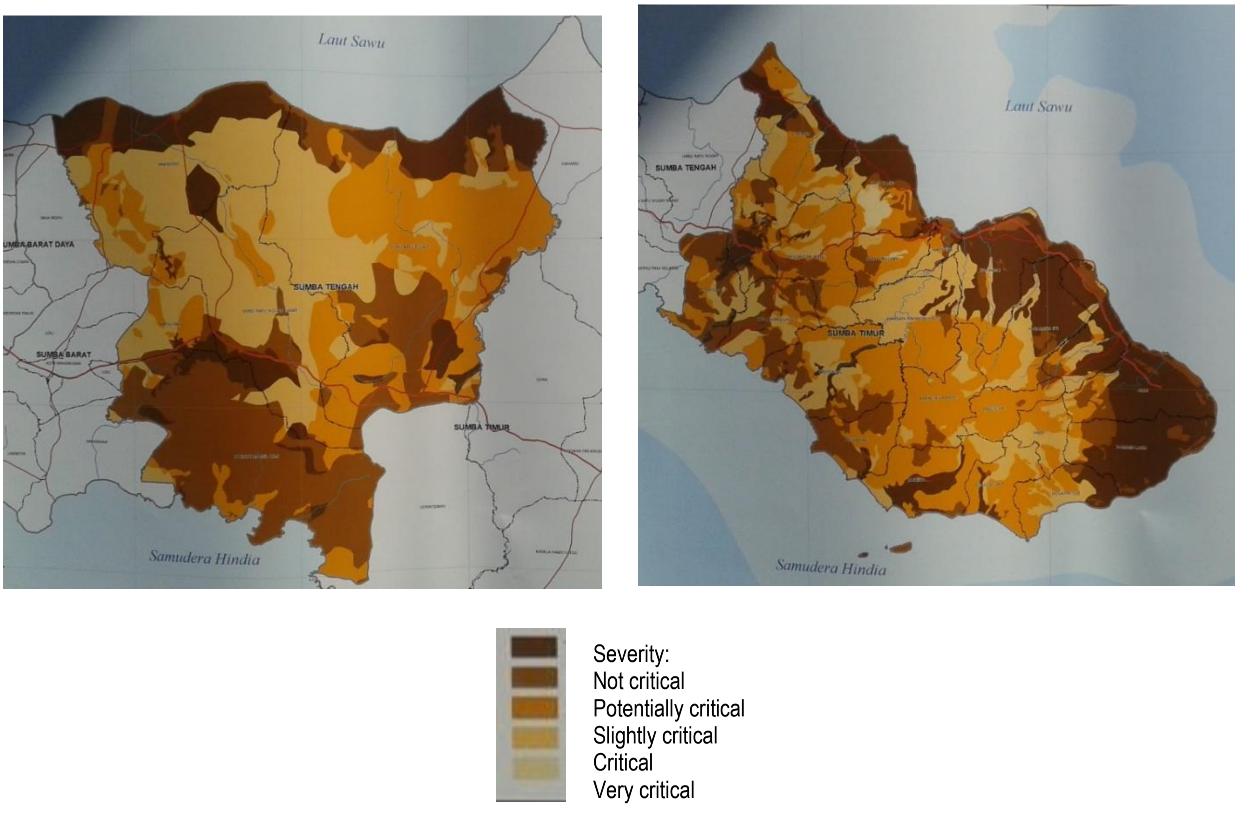


Fig. 6.4 Distribution of critical land in Central Sumba (left) and East Sumba (right) in 2013 (UGM, 2013c), (UGM, 2013d)

6.5.2 Land suitability for energy crop

Type of forest plantations that have adapted to mixed-dry land area in East Sumba include *Mahoni* (*Swietenia macrophylla*), *Jati* (*Tectona grandis*), *Gmelina* (*Gmelina arborea*), *Nangka* (*Artocarpus integra*), *Asam* (*Tamarindus indica*), *Kesambi* (*Schleichera oleosa*), *Turi* (*Sesbania grandiflora*), *Lamtoro* (*Leucaena leucocephala*), *Akasia* (*Acacia villosa*), *Pulai* (*Alstonia scholaris*), *Mangga* (*Mangifera indica*), *Nitas (*Sterculia foetida*), Jambu hutan (*Eugenia *spp.), Singkong* (*Manihot utilisima*), *Jagung (*Zea mays*)* (Njurumana, 2008b).

Schleichera is the only oil-bearing crop in the list. It can grow on dry climate and produce fuelwood. However, it is not capable of producing nitrogen, fast growing, nor standing on saline soil. Pongamia, the crop chosen to provide the model inputs in this study (Chapter 4), has not been reported to exist in Sumba. However, a dense pongamia plantation exists on coastal area in western part of Timor, a small island located 200 km to the east of Sumba.

Soil characteristics in East Sumba are dominated by rendzina (45.30%) and cambisol (43.35%) (Anonymous (2005) in Njurumana (2008b)). East Sumba has more stony soils in the northern area, saline soils in the east and coastal area, lime soils in the central area, and steep valleys but more fertile soils in the southern area (EastSumbaForestryAgency, 2016). Around 40% of East Sumba area is steep valleys (Anonymous (2005) in Njurumana (2008b)) which majority of the slopes are arable (EastSumbaForestryAgency, 2016).

Such soil types and the climatic conditions (Section 6.2) in Sumba indicate suitability for growing pongamia trees (Chapter 4). Besides soil types and the climate, the soil quality was also assessed. The fertility of the soil was assessed through a test that was carried out to six samples from six points in five districts in East Sumba and Central Sumba, to represent the variety of soil types. Determination of the sampling points was assisted by the forestry agency officers who have the capability related to their job responsibility. Each location provides a sample, except Hamba Praing that provides two sampling locations because of the large difference between the two. The six sampling locations with each code are Hamba Praing 1 (HP1), Hamba Praing 2 (HP2), Pambotanjara (PJ), Laipori (LP), Lawonda Maderi (LM), and Cendana (CD) (Fig. 6.5). The soil and the landscape at the sampling locations are shown in Figs. 6.6a – 6.6f.

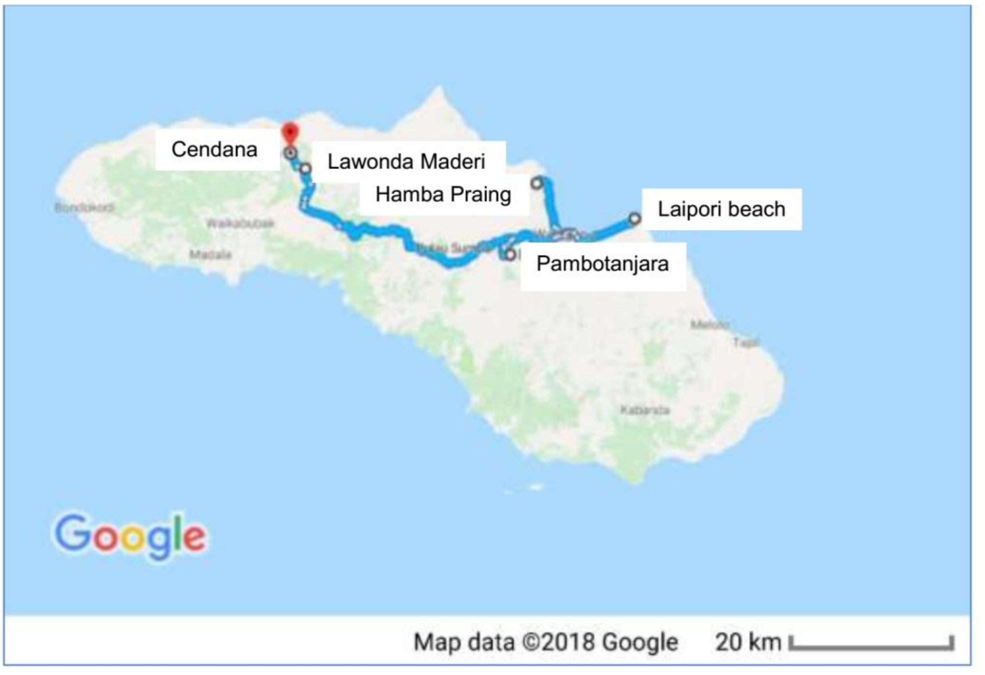


Fig. 6.5 Locations of the five critical land areas where soil samples were taken (retrieved 13th Aug 2018)

The soil test result was compared to a soil test result from a reference site in Indonesia, namely Parung Panjang that has proven pongamia oilseeds productivity in the fifth year of growth. Parung Panjang is a marginal land area in Java island where pongamia trees were grown in 2011 and had the first oilseeds harvest in 2016 early. Although the precipitation is quite high 2,000-2,500 mm/year, the soil has poor nutrients, high acidity, and contains aluminium that can inhibit plant growth (BPTPB, 2012).

The parameters that were tested include the content of organic carbon (C-org), nitrogen (N), phosphorous (P), potassium (K), exchangeable cations and cation exchangeable capacity (CEC), and the soil texture (Table 6.1, Appendix B). Soil organic carbon reflects overall soil health and the concentration is in line with CEC, total N, water-holding capacity, and microbiological activity. The N, P, and K content in the soil influences plant growth, while the exchangeable cations and the CEC affect plant growth or yield. Particularly, the N-fixing capability of a crop is important to avoid the N-based component being leached from the soil by the excessive contact of water. (Horneck, Sullivan, Owen, & Hart, 2011)

According to the typical characteristics for soil fertility (Horneck et al., 2011), all samples had adequate C-org, and low P. The K content was high in three samples (CD, HP1, and LP), low in one sample (LM) and the reference, and very low in two samples (HP2 and PJ). (Table 6.1)

The soil test results show that for all parameter values except the nitrogen content, the majority of the samples have better fertility profile than Parung Panjang's, the reference. Compared to the reference soil, the samples except HP2 and PJ have lower nitrogen concentration, due to the reference land has grown pongamia, the existing N-fixing crop. Two samples (HP2 and PJ) show a lower organic carbon, potassium, and cation exchangeability, while one sample (HP2) has lower phosphorous (Table 6.1).

HP2 and PJ show inferior quality in term of N, P, K, and CEC. The inferiority can be overcome by adding required elements only when planting the trees, as what was applied in Parung Panjang.

Besides the soil nutrient, the water consumption and the soil acidity also influence the crop suitability and productivity. The rainfall in the sampling locations (500-2,500 mm/year) (Section 6.2), is similar to Parung Panjang (2,000-2,500 mm/year). In term of soil pH, all Sumba soil samples were better than Parung Panjang. Unlike the acidic Parung Panjang soil, they were neutral with pH around 7 which meet the optimum soil pH for most plants at 6.0 – 8.2 (Horneck et al., 2011).

Overall, based on the climate and soil characteristics, it is likely that pongamia can grow on Sumba marginal lands at various productivity and possibly better than Parung Panjang. However, the decision of what crop to cultivate should be up to the investor based on sufficient assessment (Chapter 4).

Table 6.1 Results of soil fertility test for Sumba marginal land

Sample	Organic carbon (C-org)		Nitrogen (N-total)	P (phosporous)		K (potassium)	
	Result	Standard	Result	Result	Standard	Result	Standard
Unit	%	%	%	ppm	ppm	ppm	ppm
Hamba Praing 1 (HP1)	4.42	>=0,5%	0.32	13.82	low (<20)	370.5	high (250-800)
Hamba Praing 2 (HP2)	1.81	>=0,5%	0.17	4.59	low (<20)	66.3	low (<150)
Pambotanjara (PJ)	2.13	>=0,5%	0.18	9.11	low (<20)	70.2	low (<150)
Laipori (LP)	3.35	>=0,5%	0.28	12.55	low (<20)	265.2	high (250-800)
Lawonda Maderi (LM)	12.24	>=0,5%	0.41	11.65	low (<20)	179.4	medium (150-2
Cendana (CD)	3.63	>=0,5%	0.27	13.45	low (<20)	265.2	high (250-800)
Parung Panjang (reference)	2.29	>=0,5%	0.37	8.9	low (<20)	101.4	low (>150)

Sample	Exchangable cations					Cation Exchange Capacity (CEC)	Soil texture fraction			pH	Rainfall
	$^{+}$Ca	$^{+}$Mg	$^{+}$K	$^{+}$Na	Total	CEC	Sand	Dust	Clay		
Unit	cmol/kg	cmol/kg	cmol/kg	cmol/kg	cmol/kg	cmol/kg	%	%	%		mm/year
Hamba Praing 1 (HP1)	98.51	3.68	0.95	0.8	103.94	45.56	26.72	34.78	38.5	7.29	1,001-1,500
Hamba Praing 2 (HP2)	56.01	1.78	0.17	0.7	58.66	17.43	47.56	33.26	19.18	7.52	1,001-1,500
Pambotanjara (PJ)	85.23	5.19	0.18	0.42	91.02	21.39	52.8	32.72	14.48	7.5	500-1,000
Laipori (LP)	59.32	1.28	0.68	0.77	62.05	58.93	23.69	40.77	35.54	7.48	500-1,000
Lawonda Maderi (LM)	85.54	4.29	0.46	0.72	91.01	67.75	7.52	51.2	41.28	7.11	2,001-2,500
Cendana (CD)	66.25	0.69	0.68	0.55	68.17	41.6	6.26	40.68	53.06	6.92	2,001-2,500
Parung Panjang (reference)	5.99	12.89	0.26	0.23	19.38	27.9	28.8	13.5	57.7	4.3	2,000-2,500

Fig. 6.6a Soil sampling on a critical land at Hamba Praing 1 (HP1), East Sumba (30th May 2016)

Fig. 6.6b Soil sampling on a critical land at Hamba Praing 2 (HP2), East Sumba (30th May 2016)

Fig. 6.6c Soil sampling on a critical land at Pambotanjara (PJ), East Sumba (30th May 2016)

Fig. 6.6d Soil sampling on a critical land at Laipori (LP), East Sumba (30th May 2016)

Fig. 6.6e Soil sampling on a critical land at Lawonda Maderi (LM), Central Sumba (1st June 2016)

Fig. 6.6f Soil sampling on a critical land at Cendana (CD), Central Sumba (1st June 2016)

6.6 Factors that affect the progress of marginal land development

In identifying the factors that will be inputted to the system dynamics model (Chapter 7), this study carried out semi-structured interviews with policymakers and landowners in Sumba island. The interviews were carried out on 31st May – 1st June 2016 in East Sumba and West Sumba with six government representatives and three private landowners, considering the time limitation (Appendix C).

The government officials comprised the Head for Forestry Agency of East Sumba, the Deputy Head for Energy Agency of East Sumba on behalf the Agency Head, the Head for Land Tenure Management of East Sumba, the Head for Energy Agency of Central Sumba, the Deputy Head for Forestry Agency of Central Sumba on behalf the Agency Head, and the Regent's Advisor on Development Affairs of Central Sumba. The interviews with the agency representatives were made by appointment, while the interview with the land agency official and the private landowners were undertaken based on the situation. The three private landowners lived in the area of soil sampling.

Based on the interviews, it was identified that the progress of marginal land development in Sumba before it is ready for cultivation is influenced by four main factors that involve stakeholders. Unless otherwise stated, the following explanation represents both East Sumba and Central Sumba.

6.6.1 Infrastructure readiness

Infrastructure readiness is influenced by supports from the central government and NGO. The most important support is funding for various activities, such as for improving the existing roads condition. The stony condition of the roads has reduced the land development speed and has also decreased the people enthusiasm to participate in coaching as well as cultivation due to their far distance from the land rehabilitation area.

6.6.2 Local government coordination

Local government coordination is determined by the Regent's commitment, the relative status, and the local government interest on Sumba Iconic Island (SII) program.

The Regent's commitment is key in local government coordination, and it is also affected by the central government support. The Regent's commitment usually plays the most important role in decision making, and the Regent's recommendations are normally obeyed by the Agencies' officials. For example, in ego-sectoral issues in East Sumba, when the forestry agency needs to lift underground water for irrigation, but the mining and energy agency which is the domain agency could not act, the project could not start as there was no command nor operational steps from the Regent. Another example, the local Development Planning Agency (Bappeda), which hierarchically has the same level of power with the forest agency and the energy agency, sometimes act as though it is the most powerful institution, that an idea that they have accepted is not executed. In the two examples, a command from the Regent is required to make the program works. Thus, the lack of joint commitment by the local government representatives can be resolved by the Regent's strong commitment.

Unlike East Sumba, Central Sumba did not face an ego-sectoral problem. The local government coordination was strongly supported by the relative status between most officials in local government institutions that reduces the potential of conflict.

Another factor that influences the local government coordination is the enthusiasm of the Executives and the Legislatives for Sumba Iconic Island (SII) program (Section 6.3) that was launched by the central government. Utilization of marginal land for energy crop supports the SII program which is very important for Sumba energy, economic, and environmental development.

6.6.3 Private landowners' willingness to cultivate

Programs of crop planting for land rehabilitation in Sumba have been running through supports from both the government and NGO. Based on existing progress, the private landowners' willingness to cultivate is driven by the income continuity over the cultivation period, the landowners' understanding, and the landowners' respect to the government.

The local government emphasized that getting income over the cultivation period is very important in establishing market certainty. It is important to keep the farmers' spirit because they tend towards being impatient to get a result. Getting income from growing energy crop on marginal land could reduce the farmers' tendency to burn forest due to financial motives such as hunting and producing grass for feedstock (Section 6.4).

In the current system, once the seedlings and all allocated funding are given to the farmers, the rights for cultivating, harvesting and selling the crops belong to the farmers, while the right of technical coaching belongs to the Forestry Agency. The success level of this system is around 70% which is high because the farmers have full right for all the economic values. However, when the economic right was not fully granted to the farmers, they did not show responsibility for maintaining the land, even they would easily ignore the notice for an inspection schedule.

All of the farmers confirmed that the most important thing for them is the crop harvest and a guarantee of income. The private landowners implied that it was difficult to get income from their marginal land. Two of them used part of their marginal land for growing and harvesting 100 kg corn per year supported by water from a 20 m depth well. The other landowner could not use their land for their usual crop due to too low precipitation. They thought that five years of waiting for the first harvest would be too long.

In handling the issue of income continuity, intercropping and silvopasture are suitable agricultural technique options for pongamia crops area that can generate income over the cultivation period (Section 4.4). Heterogeneous horticulture through intercropping also benefits the biodiversity and resistance to a pest, and the silvopasture can also accommodate the style of farming livestock in free nature.

A guarantee for getting income from the crop is usually received from the central government via the Regent, that informs about who will buy the crops, that can be supported by research results. For example, the cultivation of *"Jati Super"* crop that has run well due to market certainty.

Landowners' understanding of the program benefits and how to participate appropriately can increase through supports from central government as well as NGO and approach by ethnic elders. The local government representatives stated that educative activities such as workshops, socialization, accompaniment, and intensive coaching had played an important role in the farmers' participation in land rehabilitation through improving their understanding and providing a technical guide for the implementation. For example, people have been able to supply housing wood by self-planting through a coaching program.

One of an important sources for funding the training is the federal government. However, the annual proposal from the local government for training the farmers has never been 100% fulfilled. Therefore, the local government officials that have participated in training, workshops, coaching that was facilitated by the higher level governments, in many cases could not transfer the knowledge to equip the farmers due to funding limitation.

NGOs have contributed significantly to land rehabilitation in Sumba. In a reforestation program in East Sumba that has performed for more than ten years, one of the largest NGOs has provided coaching for the farmer's groups, while The Forestry Agency provides the seedlings. The local government mentioned that it could take 3-4 years to do the training activities that includes knowledge of the crops benefit and the technical guide for cultivation.

Ethnic elders play an important role in increasing landowner's understanding as people usually obey them thanks to a feeling of close relationship. To exemplify, they successfully persuaded people to do a government conservation program even though it did not suit their tradition. Another example, some people think that many of critical lands are the heritage of their ancestors and is customary land, which is owned by a family or a group, on which nothing necessary to do. The ethnic elders' approach is usually effective through social and family approaches at the location.

Another support for the private landowners' willingness to cultivate is the high respect by the farmers to the government officials. They stated that they would keep their commitment to dedicate the crop for energy purpose. The main reason is that the program is from the government and all they need since pre-cultivation up to the crop harvesting is provided for free. However, the high respect was shown only when they are given the full economy rights in cultivating marginal land, in other words, they were usually not cooperative when they are cheated.

6.6.4 Land status clarity

Land status clarity is determined by the land certification by The National Land Agency (BPN) and the land tenure by the landowners. The land status should be clear before starting reforestation to avoid the people's envy, such as in the status clarity between the state land and the tribal lands. In 2016, around 65% of landownership in East Sumba was unclear whether it was of a clan, a person, or a state.

The land certification by BPN is affected by government support. Although BPN has worked hard for increasing land certification, land certification in East Sumba was less than 20% by May 2016. One of the problems is that the Planning for Space and Area Management ("*RTRW*") has not been provided in detail. The Land Agency at the regency level can recognize the land tenure based on the application for certification.

Land certification does not guarantee land tenure which the valid data exists at the village level. For example, the share of the central government land in East Sumba is around 420,000 ha or 60% of the total land area. However, part of the government's land has been claimed or used by people as their property for decades, and they could not be asked to move out. Although land that is owned by the government will be easier to use, the management is by farmers groups. If a forest area is a state's land, the land use authorization is issued by the Regent, otherwise the Forestry Agency.

6.7 Model Inputs

Parameters that become inputs for the system dynamics model (Chapter 7) are the growth of liquid fuel demand, the maximum available area for growing energy crops, the expected time for land preparation/development, and the factors that influence the progress of marginal land preparation/development.

- In the simulation of the liquid fuel supply and demand, the growth of liquid fuel demand in Sumba was assumed to be 5% per year (Section 6.2).
- The maximum area of marginal land that is expected available for energy crop in East Sumba and Central Sumba is 475,000 ha (Section 6.2), which should not be exceeded by the initial value (IV) for the available area of marginal land.

- Some of the consideration is the possibility for cultivation due to slope inclination and the use for the non-energy crop (Section 6.4). The cultivation area determines the impact of the DBF project to the local economic growth.
- The expected time to develop marginal land for energy crop was set at three years which covers program establishment and budgeting and education before massive cultivation. Based on the state budgeting system, it is possible for the central government to provide all funding in one year or two after the initiation of the marginal land use program on Sumba island. One of the two years is required to transfer the program from the central government to regency level, then a year more to establish it at the districts or villages. However, dealing with social matters normally takes more than two years for the dedication of marginal land for bioenergy. In East Sumba, it can take three to four years to do the educative activities in land rehabilitation (Section 6.5).

  Since 16th October 2016 (a few months after the interviews for this study), a new governmental structure has been applied to improve the bureaucracy efficiency. In the new structure, the forestry affairs excluding the community forest land (*tanah hutan rakyat)* became the provincial authority, while at regency level the government has responsibility for approaching farmers and the forestry agency to do the execution. This structure benefits management/bureaucracy efficiency because less number of powerful parties get involved in decision making.
- The support that affects the marginal land development consists of four main factors which each are elaborated into more specific variables. (Section 6.5). The factors are arranged on the system dynamics model as variables that are connected through causal relationships (Chapter 7).

6.8 Conclusions

Having significant liquid fuel demand, no petroleum oil resources, and abundant marginal land area, Sumba Island can be a good study case island in assessing marginal land use for growing crops for liquid biofuel production in Indonesia.

Based on the analysis on the Sumba climate and the soil test result, pongamia, the preferable crop, is likely suitable for cultivation on Sumba marginal lands. However, decision of the crop type should be up to the investors based on a further analysis before starting the cultivation.

The progress of marginal land development for energy crop in Sumba can be affected by four main factors which are influenced by the sense of urgency by the President in increasing liquid fuel self-sufficiency (Chapter 2), namely:

- infrastructure readiness;
- local government coordination;
- private landowners’ willingness to cultivate, and
- land status clarity.

CHAPTER 7
DEVELOPING THE SYSTEMS DYNAMICS MODEL

7.1 Introduction

This chapter describes the process through which all variables and relationships take place in a simulation for the assessment, using mathematical modelling. The model *Assessment Tool of Biofuel Strategy through Utilization of Marginal Land and Innovation in Conversion Technology* (ABMIC) was built through integrated inputs as described in Chapters 2 to 6. Chapter 2 provides the rationale as well as inputs regarding the Indonesian situation of liquid fuel supply and demand. Then, Chapter 3 provides the framework as well as some inputs to the model. Chapters 4, 5 and 6 provide other specific inputs around the issues of marginal land, technology innovation, and the case study island.

To meet the objectives, the modelling process involved several main stages by applying system dynamics methodology ((Maani & Cavana, 2007); Sterman (2000)):

- problem structuring,
- causal loop modelling,
- dynamic modelling,
- model validation, and
- policy experiment.

This chapter covers the stages up to building the dynamic model, while the model validation and policy experiment stages are covered in Chapter 8.

Section 7.2 formulates the problem in the context of systems thinking. Section 7.3 discusses causal interactions that were identified, followed by Section 7.4 that lists the model boundaries. Section 7.5 describes the data and information gathering in developing the system dynamics model and Section 7.6 describes the whole structure of the model.

7.2 Problem formulation

The problematic behaviour in the system revolves around the liquid fuel self-sufficiency in Indonesia. The demand is increasing while the fossil resources for liquid fuel production are declining. On the other hand, the utilisation of renewable resources for liquid biofuel production is low and fluctuating (Chapter 2). In handling the liquid fuel self-sufficiency problem, this study proposed the implementation of an integrated strategy to utilize marginal land for biomass feedstock provision linked with appropriate conversion technology for enhancing liquid biofuel integration with the existing fossil fuel system.

The purpose of developing the ABMIC model was not to forecast liquid biofuel supply and demand, nor to predict when a certain state of conditions could be achieved. The purpose was to provide insights about policy implications in liquid biofuel development for increasing liquid fuel security in Indonesia through the utilization of marginal land and appropriate conversion technology by 2045. Therefore, learning the behaviours generated throughout the system was considered more important than predicting the value of the system's performance in the future.

7.3 Causal loop modelling

In viewing the big picture of the problem, causal loop modelling was carried out to provide explanation of the interrelationships between the main variables involved and the patterns that are generated. The causal loop modelling was started by identifying the main variables followed by developing a causal loop diagram. Then, the dynamics of the main variables implied by the diagram were analyzed followed by identifying the system archetype that can describe the high-level causal patterns and identify the key leverage points. Finally, strategies for intervening the key leverage point were developed.

7.3.1 Identification of main variables

In the implementation of the strategy, the main supporting conditions and barriers were identified and listed (Table 7.1).

Considering the supports and barriers, the main variables in Indonesian liquid fuel self-sufficiency system were identified, namely national liquid fuel self-sufficiency, oil fuel imports, biofuel implementation, and support for drop-in biofuel (DBF) production.

Table 7.1 Supports and barriers in increasing liquid fuel self-sufficiency in Indonesia through the utilization of marginal land and appropriate technology for biofuel production

Supports	Barriers
High demand for liquid biofuel implementation to substitute the high oil fuel import.	The high oil fuel import decreases the balance of trade and thus decreases financial capacity for supporting biofuel implementation
Policy for using liquid biofuel at high concentration (30%) exists.	Significant effort that reflected urgency in liquid biofuel implementation was usually only when the balance of trade is a deficit or existing biofuel is cheaper than oil fuel.
Technology for drop-in biofuel (DBF) production is developed and expected to be technically ready at commercial scale in 2023 if the research funding support is continued.	Prices for petroleum fuels have been usually cheaper than liquid biofuel.
In implementing DBF technology, palm oil can be used before feedstock from marginal land is ready.	Concentration of oxygenated biofuel use has technical limitation.
A large area of unused marginal land exists in many islands for growing energy crops.	Funding in DBF technology development lacked continuity.
Some islands have low or zero petroleum oil resources but significant area of marginal land.	Support for marginal land use for energy crop production was not significant.
Positive results are available from advanced research about the cultivation of *Pongamia pinnata*, an oil-bearing energy crop on marginal land.	The strategy is cross-sectoral therefore implementation needs urgency from the high-level policymakers.

7.3.2 Developing a causal loop diagram

The main variables determined in the previous section are put in a causal loop diagram to see the relationships among variables the main feedback loops and the pattern implied, and to provide an endogenous explanation of the system.

A causal loop diagram consists of variables that are linked by arrows and loops. The arrows have two polarity types:

(i) Positive (+) arrows mean that the cause will augment the effect or has the same direction of change, and

(ii) Negative (-) arrows mean that the cause will shrink the effect or has the opposite direction of change.

The feedback loops consist of two types:

(i) Reinforcing (R) or positive feedback loops, formed by an even number of negative arrows meaning that they are strengthening the feedback loop, and

(ii) Balancing (B) or negative feedback loops, formed by an odd number of negative arrows meaning that it is goal-seeking the feedback loop.

The simple causal loop diagram consists of two balancing loops (B1 and B2) (Fig. 7.1). The main problem symptom of liquid fuel self-sufficiency can be lessened by oil fuel imports or biofuel implementation. Balancing loop B1 shows that an increase in liquid self-sufficiency problem drives up oil fuel imports. Balancing loop B2 shows that, after a delay, the liquid fuel self-sufficiency problem drives up biofuel implementation. Oil fuel imports are a quick solution which has been mainly chosen in overcoming the problem. On the other hand, biofuel implementation as the fundamental solution remained low and fluctuating, despite the abundant availability of resources. Moreover, the crude oil resource is declining while liquid fuel demand is increasing (Chapter 2).

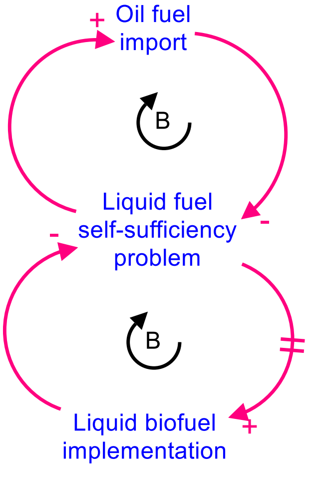


Fig. 7.1 Simple causal loop diagram for liquid fuel self-sufficiency problem in Indonesia

The simple causal loop diagram was then expanded to four reinforcing loops (R1, R2, R3 and R4) and six balancing loops (B1, B2, B3, B4, B5 and B6) (Fig. 7.2).

Balancing loop B3 shows that liquid fuel self-sufficiency problem drives up oil fuel imports which leads to an increase in foreign exchange demand and hence a decrease in the balance of trade. The decreasing balance of trade reduces the pressure and thus increases the sense of urgency by the President. This drives the liquid biofuel consumption target upwards which leads to an increase in liquid biofuel implementation. An increase in liquid biofuel implementation results in a decrease in liquid fuel self-sufficiency problem. Due to data limitation, local currency valuation was excluded from the model boundary.

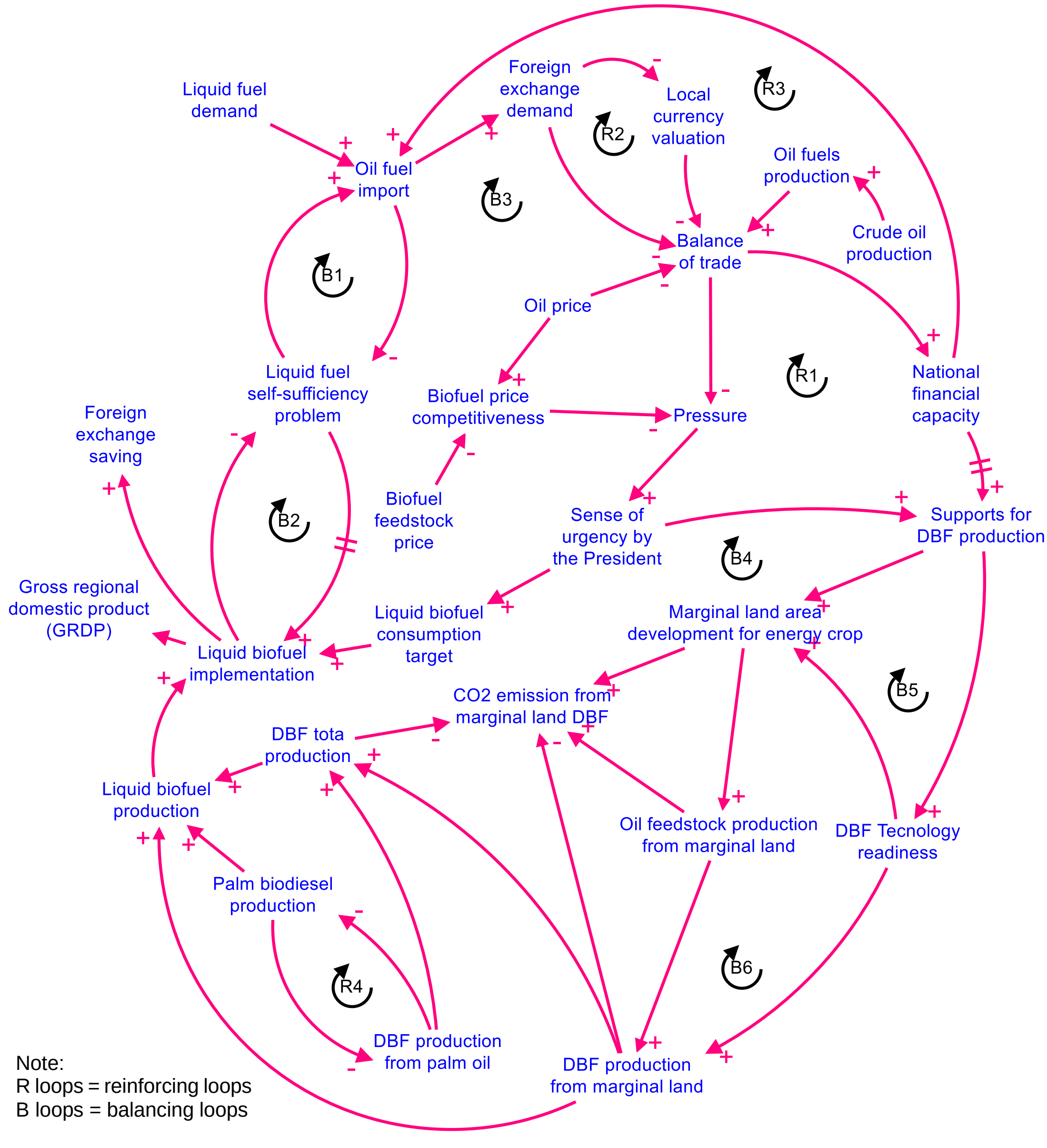


Fig. 7.2 Expanded causal loop diagram for liquid fuel self-sufficiency problem in Indonesia

Balancing loops B4, B5 and B6 show that a problem of liquid fuel self-sufficiency drives up oil fuel imports which leads to a decrease in the balance of trade which in turn reduces the pressure from the balance of trade and thus increases the sense of urgency by the President which, in turn, drives up support for DBF production.

Balancing loops B4 and B5 show that support for DBF production has positive impacts on marginal land area development for energy crop directly (balancing loop B4) as well as indirectly through an increase in DBF technology readiness (balancing loop B5). Marginal land area development for energy crop production leads to an increase in oil feedstock production from marginal land and hence an increase in DBF production which increases liquid biofuel production. This results in increasing liquid biofuel implementation and thus reduces liquid fuel self-sufficiency problem.

Balancing loop B6 shows that an increase in support for DBF production increases DBF technology readiness which leads to an increase in DBF production from marginal land, and thus DBF total production and liquid biofuel production. The increase in liquid biofuel production increases liquid biofuel implementation which in turn reduces liquid fuel self-sufficiency problem.

There are interesting dynamics in balancing loops B3, B4, B5 and B6 where oil fuel import drives down the balance of trade which leads to an increase in urgency. An increase in the sense of urgency eventually leads to increasing liquid biofuel implementation meaning that the liquid fuel self-sufficiency problem decreases, thus decreasing oil fuel import.

Reinforcing loop R1 shows that a liquid biofuel self-sufficiency problem drives up oil fuel imports which leads to a decrease in the balance of trade which in turn reduces national financial capacity. After a delay, a decrease in national financial capacity decreases the support for DBF production which drives down the progress in marginal land area development for energy crops as well as DBF technology readiness, which leads to a decrease in liquid biofuel implementation and thus an increase in the liquid fuel self-sufficiency problem.

According to reinforcing loop R2, an increase in oil fuel imports leads to an increase in foreign exchange demand and thus a decrease in local currency valuation. A decrease in local currency valuation decreases the balance of trade which results in increasing pressure that drives up the sense of urgency by the President which results in an increased liquid biofuel consumption target and consequently increased liquid biofuel implementation. This reduces the liquid biofuel self-sufficiency problem which leads to a decrease in oil fuel import. Due to data limitation, foreign exchange demand and local currency valuation variables are excluded from within the model boundary.

Reinforcing loop R3 shows that oil fuel imports increase foreign exchange demand which in turn weakens the local currency valuation and thus decreases the balance of trade, thereby decreasing national financial capacity leading to a decrease in oil fuel imports. At some point, when financial capacity becomes too low, it leads to an economy collapse. Considering the purpose of the model and data limitation, the national financial capacity was excluded by the model boundary.

Reinforcing loop R4 describes the transition from production of palm biodiesel which is the existing liquid biofuel, to palm DBF. This loop shows that an increase in DBF production from palm oil decreases palm biodiesel production which results in increasing DBF production from palm oil.

7.3.3 Identification of system archetype

Identification of system archetype is useful in designing an intervention. Out of the eight most common system archetypes (Maani and Cavana (2007); (Senge, 1990)), the most representing type is the "shifting the burden" archetype (Fig. 7.3).

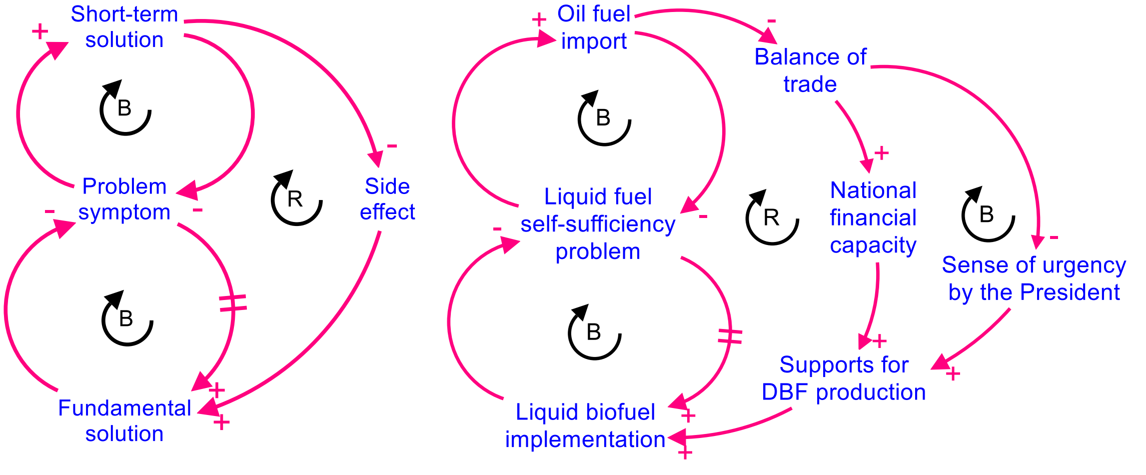


Fig. 7.3 Left: "Shifting the burden" archetype; Right: high-level causal patterns

The high-level causal patterns imply a "shifting the burden" archetype. In overcoming the liquid fuel self-sufficiency problem, biofuel implementation is the fundamental solution available yet policymakers are procrastinating. Instead, importing oil fuel has been mainly chosen as a short-term solution, which drives up the balance of trade as the side effect (Chapter 2). This leads to a decrease in financial capacity which in turn decreases supports for DBF production and thus biofuel implementation. As well as decreasing national financial capacity, a decrease in the balance of trade results in an increase in the sense of urgency which drives up supports for DBF production and hence liquid biofuel implementation.

7.3.4 Identification of key leverage points

The expanded causal loop diagram (Fig. 7.2) shows that the sense of urgency by the President (SU) is passed through by four loops, namely B3, B4, B5 and B6, which is the largest count of loops passing through a variable. Thus, SU is considered the key leverage point of the system.

7.3.5 Developing intervention strategies

In improving the system's performance, a strategy for intervening the key leverage point was designed. To shift the system's concern to the loop of biofuel implementation, it is necessary to increase the drivers, namely national financial capacity and/or sense of urgency. National financial capacity is limited and has many other allocations. For financial optimization, the strength of the loop of national financial capacity can be reduced by strengthening the loop of urgency. However, sense of urgency has been fluctuated responsively to the balance of trade. Therefore, intervening urgency by an anticipative driver such as future vision (Chapter 2), is necessary to have it stronger and more sustained.

Based on the important feedback loops in the system, a dynamic hypothesis was formulated:

The sense of urgency by the President affects the liquid fuel self-sufficiency through utilization of marginal land and appropriate biofuel technology, which in turn influences the sense of urgency itself.

Based on this dynamic hypothesis, the model boundary and the dynamics modelling were developed as described in Sections 7.4 and 7.5 respectively.

7.4 Model boundary

The main purpose of a systems dynamics model is to provide an endogenous explanation of the problem (Sterman, 2000). Therefore, the variables that influence the dynamics of the behaviour of the system should be included in the model. Deciding on what variables to be generated by the system (endogenous), those to be treated as exogenous, and the excluded ones, were based on the model purpose or the problem being analysed.

Unlike other studies that use a systems dynamics approach, this study treated policy and delay as endogenous variables (Chapter 3).

Based on the model's purpose, the boundaries for the model were set as shown in Table 7.2.

Table 7.2 ABMIC model boundaries

Endogenous	**Exogenous**	**Excluded**
The sense of urgency by the President	Future vision power	Local currency valuation
Liquid biofuel share target	Weight to vision	National financial capacity
Balance of trade	Oil price	Land mapping
Fuel price difference	Gas price	Crops other than pongamia
Liquid biofuel consumption value	Crude palm oil price	Oxygenated biofuel other than palm biodiesel
Liquid biofuel export value	Crude oil export volume	Differentiation of DBF
Technical readiness (TR)	Crude oil import volume	
Supports on technology readiness	LPG import volume	
Year of technology commercially ready	LPG export volume	
Sumba developed marginal land area	Gas export volume	
Marginal land area available for bioenergy	Gas import volume	
Actual year of planting start	Non-oil & gas export value	
Year of DBF production starts	Non-oil & gas import value	
Desired year of pongamia oil feedstock ready	Expected time to progress TR	
Year of pongamia oilseeds ready	The maximum area of marginal land area available for bioenergy	
Pressure from TR to land development	Expected time to have marginal land prepared	
Supports' effect on marginal land preparation time	Weight to pressure from TR on land development	
Government support for infrastructure	NGO support	
Government support for the Regent's commitment	Fraction of Government support	
Government support for Sumba Iconic Island (SII) program	Approach to farmers by ethnic elders or association	
Government support for income guarantee	Crop rotation cycle	
Government support for landowners’ understanding	Time length from cultivation to the first harvest	
Sumba DBF production	Crop growth rate	
National DBF production from marginal land	Oilseeds yield	
Desired new DBF capacity	Marginal land feedstock management	
DBF capacity under construction	National/Sumba area multiplier	
DBF production capacity	Oil feedstock conversion factor	
Sumba DBF supply	Desired DBF production per plant	
Sumba DBF consumption	Sumba liquid fuel demand	

Endogenous	Exogenous	Excluded
Sumba DBF for export	DBF fraction for diesel	
Sumba liquid fuel import demand	Concentration of diesel combustion booster	
National DBF production	Biodiesel existing mandate	
Biodiesel capacity under construction	CPO productivity target	
Biodiesel production capacity	DMO palm oil	
National biodiesel production	Fraction palm oil for food and oleo excluding biodiesel	
Added biodiesel capacity	National liquid fuel demand	
National biodiesel supply	National oil fuels production	
National DBF consumption	DBF export quota	
National biodiesel consumption	Biodiesel export quota	
CPO average productivity	Pongamia oil feedstock cost growth rate	
Palm oil supply for biodiesel and DBF	DBF profit margin	
Palm oil available for DBF	CPO price	
Palm oil demand for biodiesel	Biodiesel converting cost	
National liquid biofuel supply	Diesel electricity emission factor	
National liquid biofuel consumption	Woodfuel electricity emission factor	
National liquid biofuel surplus	DBF CO_2 emission factor	
National liquid fuel import demand	Fossil fuel CO_2 emission factor	
Pongamia oil feedstock cost	C stock open land	
Foreign exchange saving	Carbon stock per tree	

7.5 Data and information gathering

7.5.1 Methods

Data and information used for developing the model were collected through various methods including analysis of government documents and other literature, interviews with landowners, interviews with policymakers, focus group discussions, and discussions with local experts both formally and informally. Most data and information were processed in Chapters 2-6 to be inputs for the relevant sub-models. Due to limitation of time, information and data for marginal land-related analysis were specifically applied to Sumba island only (Chapter 6), which was then roughly projected to the national level to estimate the impact at country level.

The first field visit for data collection was carried out in May – June 2016 for a soil suitability test which was required for assessing the suitability of *Pongamia pinnata*, the energy crop candidate, on Sumba marginal land (Chapter 4 and 6). The interviews and discussions were carried out during several different visits in May 2016 – May 2017.

Interviews with landowners and local policymakers in Sumba Island were conducted in May – June 2016, to get insights about parameters that can affect marginal land preparation for bioenergy production. The semi-structured interviews involved six private landowners in two targeted regencies (Chapter 6), and policymakers from the forestry agency and the energy agency (Appendix C).

In December 2016, a focus group and a few interviews with local experts and federal government officials were held to get a big picture of policy that was adopted in Chapters 2-7, combined with literature analysis.

In April 2017, a discussion was conducted with a soil expert for increasing confidence in analyzing marginal land use for growing an energy crop (Appendix H).

In building the technology readiness sub-model (Chapter 5), the information and data were collected through (i) literature analysis; (ii) informal discussions with the technology experts (December 2015 - June 2016); (iv) a focus group discussion in November 2016, and (iii) site visits to the R&D facility of DBF technology development (November 2016 and May 2017). These provided insights in determining the significant variable in technical technology readiness.

The last field visit was undertaken in April – May 2017 to gain insights/advice/inputs from multi-stakeholders in order to improve, adjust, refine and enrich the model.

7.5.2 Ethical considerations

Undertaking the interviews and focus groups fell within Massey University's requirements and guidelines for a Low Risk Notification. The documentation for *Notification of Low Risk Research/Evaluation Involving Human Participants* was completed, and approval to proceed was received on 17th September 2015 that the project was recorded on the Low Risk Database which is reported in the Annual Report of the Massey University Human Ethics Committees. In undertaking this research, the Code of Ethical Conduct for Research, Teaching and Evaluations involving Human Participants was complied with. All participants were sent an information sheet (Appendix A2) with full information about the research and including statements of their rights. All participants completed a Participant Consent Form (Appendix A4).

7.6 Model structuring

7.6.1 Model description

A system dynamics model consists of at least three main components:

(i) state of condition which is visualised as "level/stock/accumulator"; that models processes;

(ii) decision point as "rate/flow" that exists between the stocks, and

(iii) feedback loops that produce the complex behaviour.

In the simulation, this study utilised the modelling software Stella® Architect - version 1.5.2. Operationalisation of the model in Stella is visualised through three types of building blocks called stock, flow, and converter. (Fig. 7.4).

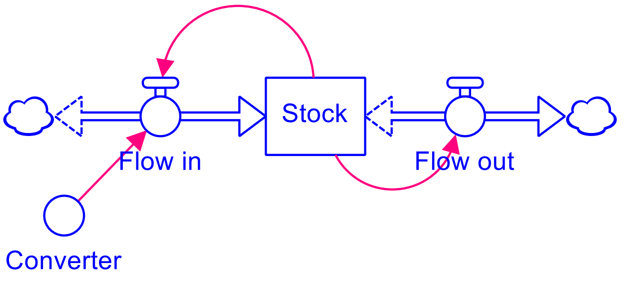


Fig. 7.4 A stock and flow diagram using Stella® Architect v1.5.2 software

A stock accumulates and stores something; it collects whatever flows into it and loses whatever flows out of it. Changes are only by flows that add and reduce accumulations.

For bi-flows in the model, the dashed arrow head points the positive (source) flow, while the solid arrow points to the negative (sink) flow.

A converter building block converts inputs into outputs to simplify the calculation process, such as (i) holding values for constants; (ii) defining external inputs to the model; calculating algebraic relationships; and (iv) serving as the repository for graphical/tabular functions.

There are three types of converter:

(i) standard converter that is useful for various purposes;

(ii) delay converter that has some of the properties of a stock, that unlike other stock types, it can be involved in feedback loops in which no explicit stock exists, and

(iii) summing converter that adds together values for a set of model variables.

The ABMIC model is divided into ten sub-models that cover local and national levels (Fig. 7.5). The local sub-models consist of marginal land use development, biofuel feedstock production, DBF production, DBF supply and demand, impact on the gross regional domestic product (GRDP), and CO_2 emissions reduction. At the national level, simulations are carried out on policy, DBF technology readiness, liquid biofuel supply and demand, impact on foreign exchange saving, and national CO_2 emissions reduction. As the land issue was observed only at local level, a multiplier to change the local level to the national level was applied for estimation of DBF production at the national level.

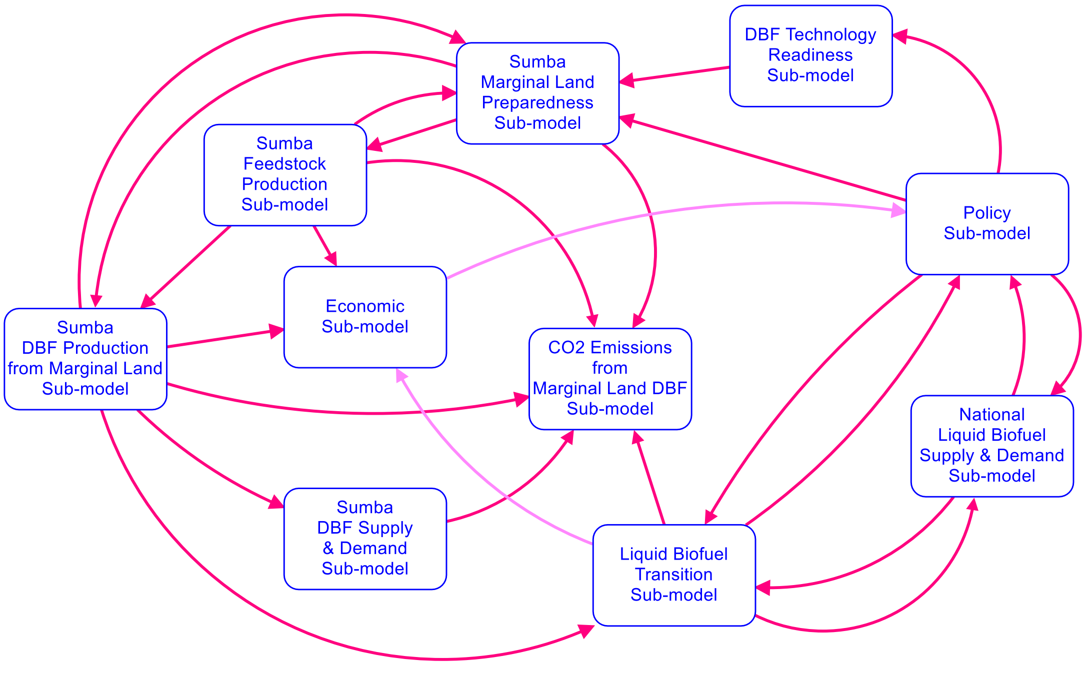


Fig. 7.5 Ten sub-models in the ABMIC model

The time horizon for the assessment ranges from 2018 to 2045 because it is the 100th Indonesian Independence Day which has been put as an important time point in the national planning and evaluation (Chapter 2).

Selected key variables and equations used in the model are outlined below with details of the other variables and equations provided in Appendix J.

7.6.2 Policy sub-model

The role of a sense of urgency in the implementation of an innovative strategy was exemplified by the USA during World War II when there was an aviation fuel shortage which was critical for defence. The purpose of the strategy was to produce aviation gasoline to fuel the Allied planes during World War II (Avidan, 1993). By that time, the increasing demand for transportation fuels had accelerated petroleum thermal cracking (the Burton Process). The urgent need for aviation jet fuel caused extreme speed in the development of fluid catalytic cracking, a primary technology in the petroleum refining process (the Houdry process) still used today. It took only three years from the initial concept to the first commercial production in 1942 (Hook, 1996). This rapid progress was driven by instructions from the commander of Allied Forces who guaranteed for the provision of all funding needed up to the technology commercialization stage.

In many cases, a sense of urgency is a cross-sectoral parameter that each of the stakeholders used to await to one another. Therefore, urgency should be held by the upper-level position. For example, history showed that the sense of urgency by the Indonesian President has critically influenced the progress of production technology for drop-in biofuel as the oil fuel import demand has made trouble in the economy (Chapter 2). In this study, the problem domain that requires urgency from the President is cross-sectoral at the national level. If one is late, then they will all be late. The urgency effect was applied to the progress of both the feedstock from marginal land and the conversion technology.

Policy sub-model is the heart of the whole model, which contains the leverage point, "Sense of urgency by the President" which drives the system's main performance, namely liquid fuel self-sufficiency through DBF implementation using technology innovation and marginal land-based feedstock, and the liquid biofuel share target based on pricing.

Based on the historical condition in Indonesia, the sense of urgency has been fluctuated and uncertain due to the pressure from the balance of trade and the pressure from the fuel price difference between liquid biofuel and oil fuel. In sustaining the urgency level, it is necessary to activate an anticipative driver, such as future vision (Chapter 2). In this modelling, the future vision is stated as a combination of future vision power and weight to vision.

The dynamics of a sense of urgency (SU, as a dimensionless unit) is mathematically represented as:

$$SU(t) = SU(0) + \int [r_{IU} - r_{DU}]dt \qquad \text{Equation 7.1}$$

$$r_{IU} = \frac{\left(FVS * WVS + MAX\left((PBT,\ PFD) * (1 - WVS)\right)\right)}{t_{SU}} \qquad \text{Equation 7.2}$$

$$r_{DU} = \frac{\mathrm{SU}}{t_{SU}} \qquad \text{Equation 7.3}$$

where SU(0) is initial value (IV) for the sense of urgency (dimensionless unit) assumed 1; r_{IU} *is* increasing urgency (in dimensionless unit); r_{DU} is decreasing in urgency (in dimensionless unit); PBT is pressure from BOT (in dimensionless unit); PFD is pressure from FPD (in dimensionless unit); FVS is future vision power (in dimensionless unit), and WVS is weight to vision (in dimensionless unit). SU values range from 0 to 1.

Balance of trade (BOT, in dimensionless unit) is calculated as the difference between national export value (NEV, in USD/yr) and national import value (NIV, in USD/yr). Each is calculated by multiplying the volume and price of each energy commodity used, such as oil, LPG, gas, biodiesel, and DBF. Thus:

$$BOT = NEV - NIV \qquad \text{Equation 7.4}$$

The values of volume and price were taken from projections by some international and national institutions such as the International Energy Agency (IEA, 2017b) and the Indonesian Agency for the Assessment and Application of Technology (BPPT, 2018). As systems dynamics commonly deals with non-linearity, the use of non-linear projection data was not a problem. Pressure from BOT (PBT) is a value of 1 or 0 which is determined to represent the condition whether there is pressure from BOT or not.

Fuel price difference (FPD, in dimensionless unit) is calculated as price difference between liquid biofuel and oil fuel. Hence:

$$FPD = oil\ fuel\ price - biofuel\ price \qquad \text{Equation 7.5}$$

Price of biodiesel, the existing liquid biofuel price, is dominated by feedstock price which depends on the international market price. It is usual that liquid biofuel is more expensive than oil fuel that decreases effort for liquid biofuel implementation. In contrast, when biofuel is cheaper due to the high oil price and/or low biofuel feedstock price (Chapter 2), the effort is usually maximum. Pressure from FPD is a value of 1 or

0 which is determined to represent the condition whether or not there is pressure from FPD.

This study proposed that liquid biofuel share target (BST, in dimensionless unit) is determined by the sense of urgency (SU, in dimensionless unit) and the price ratio of biofuel to oil fuel (PRF, in dimensionless unit). When PRF is more than 1, BST is the same as the urgency level. Otherwise, BST is equal to 1. Thus:

$$PRF = \frac{liquid\ biofuel\ price}{oil\ fuel\ price} \qquad \text{Equation 7.6}$$

If PRF>1, then $BST = SU$ Equation 7.7

If PRF <=1, then $BST = 1$ Equation 7.8

The stock and flow diagram of Policy sub-model is presented in Fig. 7.6.

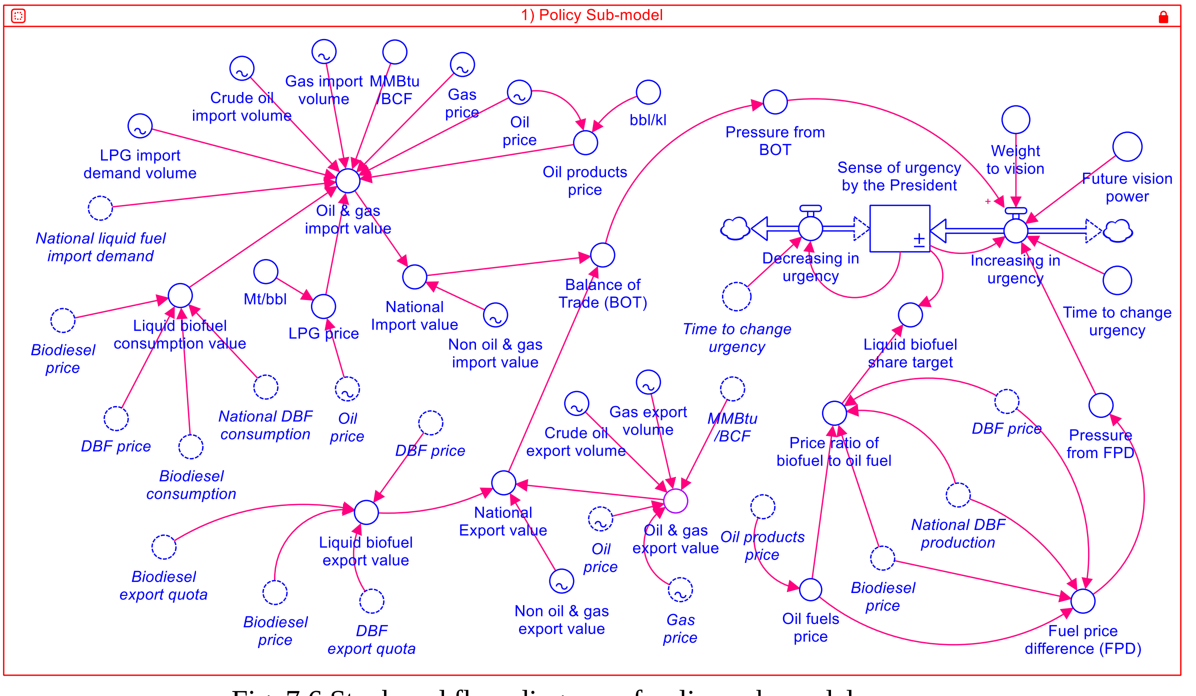


Fig. 7.6 Stock and flow diagram of policy sub-model

The rest of the parameters used in the sub-model including the parameters that come from and to other sub-models are listed in Tables 7.3, 7.4, and 7.5 respectively. All the equations for this sub-model are found in Appendix J.

Table 7.3 Parameters used in policy sub-model

Parameter	Type	Value	Unit	Notes/Source
Initial value (IV) for SU	Constant	1	dimensionless	Chapter 2

Parameter	Type	Value	Unit	Notes/Source
Time to change urgency	Constant	1	year	
Future vision power	Constant	0	dimensionless	Chapter 2
Weight to vision	Constant	0	dimensionless	Chapter 2
Gas export volume	Time series		BCF/yr	BPPT (2018)
Crude oil export volume	Time series		bbl/yr	BPPT (2018)
Non-oil & gas export value	Time series		USD/yr	(BPS, 2018a); assumed 5% growth of historical data (BPS (2018a); Chapter 2)
Non-oil & gas import value	Time series		USD/yr	assumed 5% growth of historical data (BPS (2018a); Chapter 2
LPG import demand volume	Time series		Mt/yr	BPPT (2018)
Crude oil import volume	Time series		bbl/yr	BPPT (2018)
Gas import volume	Time series		BCF/yr	BPPT (2018)
Oil price	Time series		USD/barrel	IEA (2017b)
Gas price	Time series		USD/MMBtu	WorldBank (2018)

Table 7.4 Input variables used in policy sub-model

Variable name	Sector of origin
National DBF consumption; Biodiesel export quota; DBF export quota; National liquid fuel import demand.	National liquid biofuel supply and demand sub-model
DBF price; Biodiesel price.	Economic sub-model
Biodiesel consumption; National DBF production; National DBF consumption.	Liquid biofuel transition sub-model

Table 7.5 Output variables from policy sub-model

Variable name	Sector of destination
Sense of urgency by the President	Marginal land preparedness sub-model.
Liquid biofuel share target	Sumba DBF supply and demand sub-model; National liquid biofuel supply and demand sub-model.

7.6.3 Technology readiness sub-model

Independent technology is part of sustainability dimensions (Bautista et al., 2016). New technology development for energy production depends on funding from government (Sims, Taylor, Saddler, & Mabee, 2008). Thus, government support is required such as to give cost competition with existing liquid biofuel, construction of a total energy system, and social awareness.

This sub-model aims to describe how technological readiness (TR) is changed by the progress which is determined by the provision of support for the investment by the sectors in-charge.

This study uses the indigenous DBF technology which is being developed in Indonesia as the assessment case (Chapter 5). In capturing important factors that influence the success in technology development, a focus group was held. All the key researchers in the technology development group implied that the only challenge in the research and development progress is funding continuity up to the commercialisation (Appendix D).

In this study, the supports on technology readiness increases the TR through the accumulated TR investment which are driven by the SU as an input from the policy sub-model. This sub-model simulates estimation of the future time when the technology will become commercially ready, which is further compared to the actual year of planting starts (Section 7.6.5), to assess how long the planting delay is impacted by the sense of urgency in implementing the biofuel strategy (Chapter 8).

Therefore, the dynamics of technology readiness is mathematically represented as:

$$TR(t) = TR(0) + \int r_{TR}\ dt \qquad \text{Equation 7.9}$$

$$r_{TR} = \frac{TRD*-1*INI}{t_{TR}} \qquad \text{Equation 7.10}$$

$$TRD = TR(t) - DTR \qquad \text{Equation 7.11}$$

$$t_{TR} = \frac{ETR}{STR} \qquad \text{Equation 7.12}$$

$$TR = SU \qquad \text{Equation 7.13}$$

where TR(0) is the initial value for TR assumed to be 0.5; r_{TR} is TR progress flow (in dimensionless unit/yr); TRD is TR difference (in dimensionless unit); INI is investment interval (in dimensionless unit) which is 5; t_{TR} is the time to progress technology (in years); DTR is desired TR (in dimensionless unit); ETR is expected time to progress TR (in years); STR is support for technology readiness (in dimensionless unit), and SU is sense of urgency by the President (in dimensionless unit).

TR is progressing in line with the accumulated TR investment (TI, in %) which is represented as:

$$TI(t) = TI(0) + \int r_{TI} \; dt \qquad \text{Equation 7.14}$$

$$r_{TI} = \frac{TIB*-1*STR}{t_{TI}} \qquad \text{Equation 7.15}$$

$$TIB = TI - IRT \qquad \text{Equation 7.16}$$

where r_{TI} is TR investment flow (%/yr); TIB is TR Investment balance (%), STR is supports for TR; t_{TI} is investment time (in years), and IRT is investment required for TR which is 100%.

Currently, funding support for the development both at pilot and demonstration scales has been committed. In completing the pilot scale, funding by the government via BPDPKS has been adequate. In accomplishing the demonstration scale, support was committed by a large private palm oil company, which the realisation will be influenced by the government. Further support in continually realizing the commercialization will be determined by the government (DBF-TechnologyGroup, 2016). The investment represents the present cost for gaining future revenue, such as foreign exchange saving through oil fuel import reduction.

Year when the technology is commercially ready (YTC, years) is a sum of Year of technology technically ready (YTT, years) and expected time of post-technical readiness (ETT, years). Thus:

$$YTC = YTT + ETC \qquad \text{Equation 7.17}$$

where YTT is number of years until the technology becomes technically ready and ETC is the expected time of post-technical readiness which was taken to be three years. In supporting the technology commercialization, it is necessary that market failure should be minimized by, for example, the government providing bridging institutions and risk-sharing. The bridging institution is important in facilitating the innovation diffusion, such as helping creators in recognizing potential applications or in communication to potential users. Regarding risk and innovation, the government can play a role in shaping and managing the risks and incentives by providing legal frameworks and regulations; and innovating by themselves taking on the uncertainty and risk (Martin & Scott, 2000).

The stock and flow diagram of DBF technology readiness sub-model is shown in Fig. 7.7.

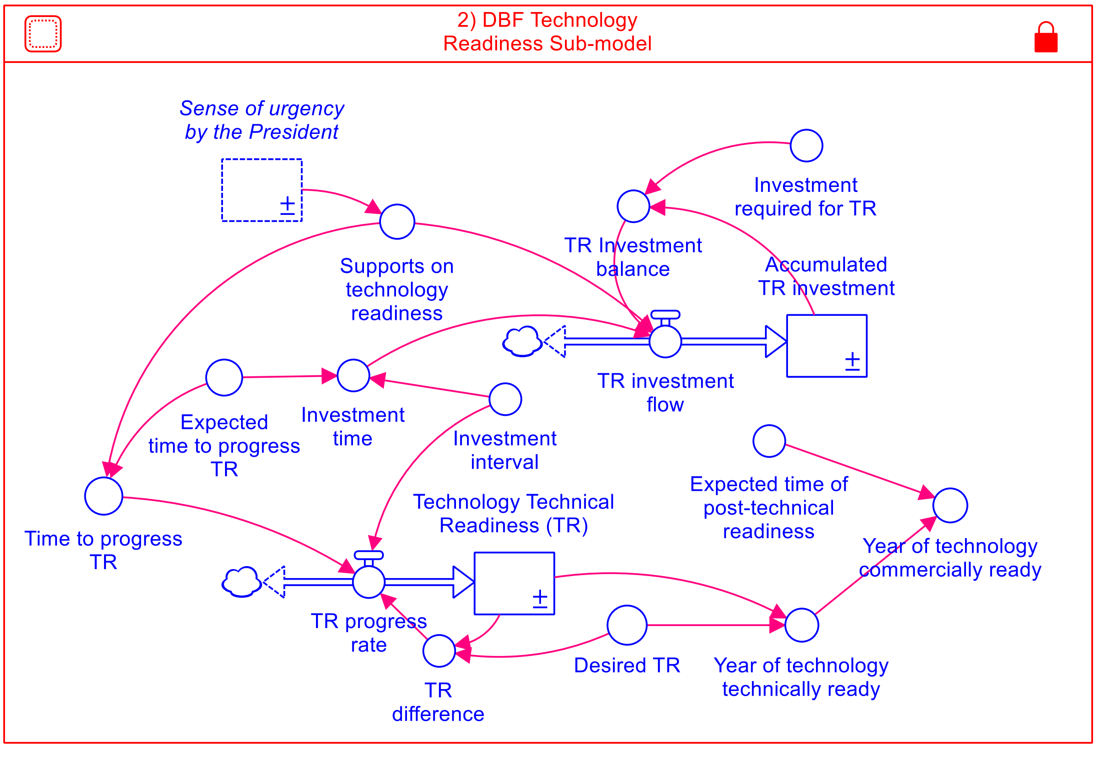


Fig. 7.7 Stock and flow diagram of DBF technology readiness sub-model

The rest of the parameters used in the DBF technology readiness sub-model, including the parameters that come from other sub-models and go out to other sub-model, are listed in Table 7.6, 7.7, and 7.8 respectively. All the equations for this sub-model are found in Appendix J.

Table 7.6 Parameters used in the DBF technology readiness sub-model

Parameter	Type	Value	Unit	Notes/Source
Initial value (IV) for technical readiness (TR)	constant	0.5	dimensionless	
Desired TR	constant	1		
Expected time to progress TR	constant	5	years	DBF-TechnologyGroup (2016) (Appendix

Parameter	Type	Value	Unit	Notes/Source
				D); Soerawidjaja (2018d) Appendix D, H
Expected time of post-technical readiness	constant	3	years	Saparita (2017)
Initial value for accumulated TR investment	constant	0	dimensionless	Appendix D

Table 7.7 Input variables used in the DBF technology readiness sub-model

Variable name	Sector of origin
The sense of urgency by the President	Policy sub-model

Table 7.8 Output variables from the DBF technology readiness sub-model

Variable name	Sector destination
Technical readiness (TR); Year of technology commercially ready	Sumba marginal land preparedness sub-model

7.6.4 Sumba marginal land preparedness sub-model

One of the main challenges in liquid biofuel industry is the feedstock cost which dominates the biofuel production cost. Developing marginal land for growing biofuel crop is a way to minimize the feedstock production cost and to increase the economic certainty.

This sub-model shows the dynamics of conversion from marginal land available (MA, in ha) for energy crop into Sumba developed marginal land area (MD, in ha), through marginal land development flow (r_{MD}, in ha/yr). The dynamics of Sumba's developed marginal land area (MD, in ha) is mathematically represented as:

$$MD(t) = MD(0) + \int [r_{MD}] dt \qquad \text{Equation 7.18}$$

$$MA(t) = MA(0) + \int [r_{MD}] dt \qquad \text{Equation 7.19}$$

$$r_{MD} = Max\left[0, \left(\frac{MA}{t_{DL}}\right)\right] \qquad \text{Equation 7.20}$$

$$t_{DL} = t_{DL0} * SMD \qquad \text{Equation 7.21}$$

where MA(0) is initial value for marginal land area available for energy crop production (in ha), assumed to be 200,000 ha; t_{DL} is actual time to develop land (in years); t_{DL0} is expected time to develop land (in years).

Supports on marginal land development time (SMD, in dimensionless unit) was calculated as:

$$SMD = (IFD * LGC * LWC * LSC) * (1 - PTR) + PTR * WTR \quad \text{Equation 7.21}$$

where IFD is infrastructure readiness, LGC is local government commitment, LWC is landowners' willingness to cultivate, LSC is land status clarity, PTR is pressure from TR to the land development, WTR is weight to pressure from TR on land development; all are in dimensionless units which range from 0 to 1. Determination of these variables was discussed in Chapter 6.

The marginal land supports value is influenced by several factors which were determined through site visits and interviews with stakeholders in Sumba island (Chapter 6). The important supporting factors comprise the pressure from technology readiness, infrastructure readiness, local government commitment, landowners' willingness to cultivate, and landowners' understanding (Chapter 6).

Each of the supports is built through an equation that involves several variables through addition and multiplication relationships. A variable is added when the role is contributing, or the existence in the system is not an obligation. On the other hand, it is multiplied when the role is dominating, or the presence is a "must" in the system. It was found that the support factors are influenced by the President's urgency as the DBF technology readiness is (previous section), so they need government support through funding and/or policy measures.

This sub-model determines the year to start crop planting which is very important for assessing the planting delay as the implication of policy intervention (Chapter 8). The year of planting reflects the delay of actual DBF production start time compared to the actual year of planting which might be required to start earlier in order to realize the DBF production start time. The required year of planting is influenced by the year of pongamia oilseeds becoming ready and the desired year for pongamia oil feedstock to be ready.

Planting delay (PLD, in year)s was determined by actual year of planting start (AYP, in years) substracted by required year of planting (RYP, in years). Thus:

$$PLD = AYP - RYP \quad \text{Equation 7.22}$$

where actual year of planting start (AYP, in years) was the year when Sumba developed a marginal land area (MD, in ha) at least equal to the land area required to support a DBF plant. For example, given the pongamia characteristics, producing

50,000 kl/yr of DBF requires at least 35,000 ha of productive land to have sufficient oil feedstock.

Required year of planting (RYP, in year) is calculated as:

$$RYP = DYF - (YDS - YPO) - TCH \quad \text{Equation 7.23}$$

where DYF is desired year of pongamia oil feedstock ready (in years), YDS is year of DBF production starts (in years), YPO is year of pongamia oilseeds ready (in years), and TCH is time length or the period of time from cultivation to first harvest (in years).

The detailed stock and flow diagram for Sumba marginal land preparedness sub-model are shown in Fig. 7.8.

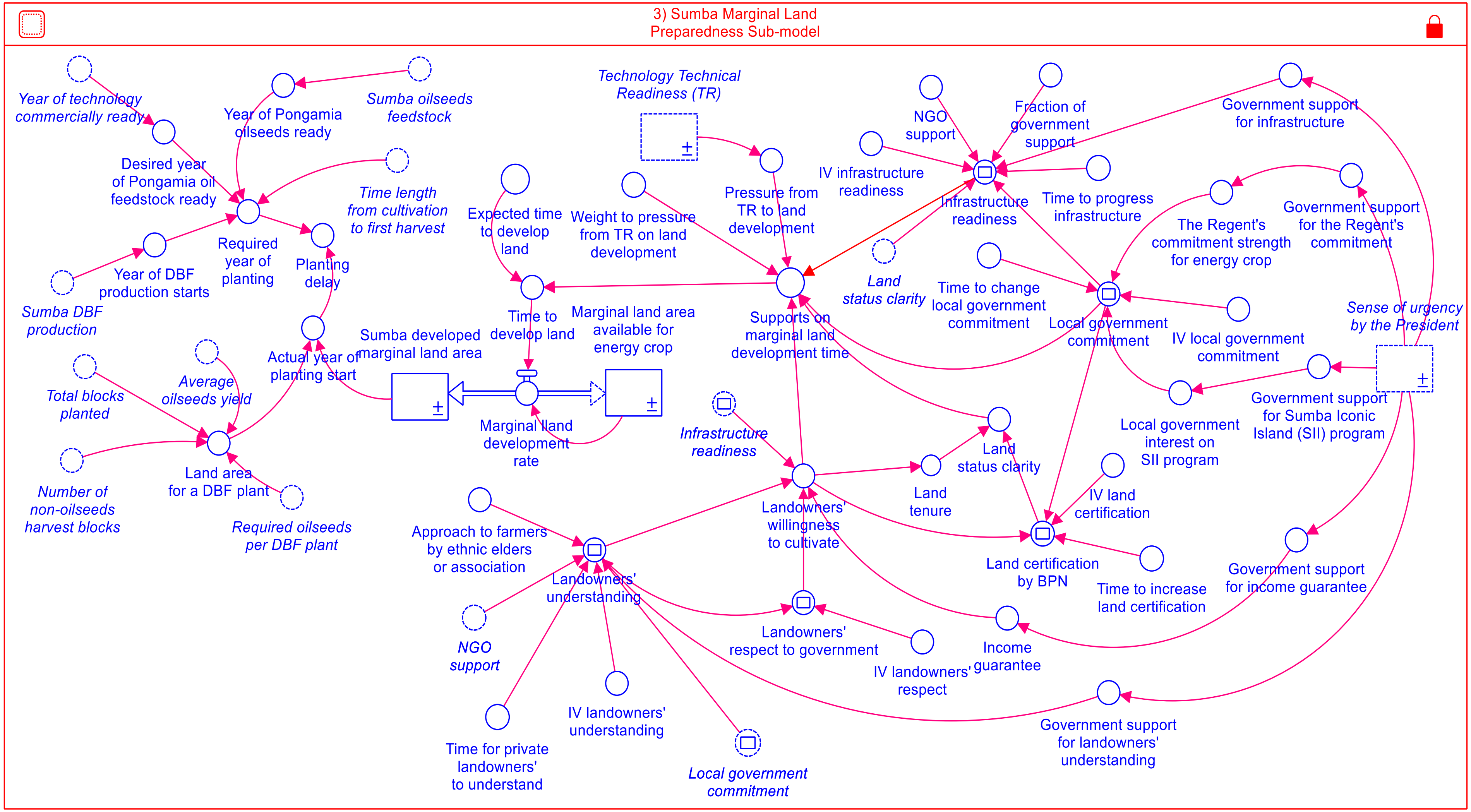


Fig. 7.8 Stock and flow diagram of marginal land preparedness sub-model

The parameters, input variables and output variables for the Sumba marginal land preparedness sub-model are presented in Table 7.9, 7.10 and 7.11, and all the equations for the sub-model are found in Appendix J.

Table 7.9 Parameters used in the Sumba marginal land preparedness sub-model

Parameter	**Type**	**Value**	**Unit**	**Notes/Source**
Initial value (IV) for marginal land available for bioenergy	Constant	200,000	ha	Required minimum area for meeting liquid fuel demand in 2045 (342k kl/yr); Considering liquid fuel demand, fruitful blocks oil yield, and oil feedstock conversion factor; Majority marginal land (total = 500,000 ha) is usable (EastSumbaForestryAgency, 2016)
IV Sumba developed marginal land area	Constant	0	ha	
Expected time to develop land	Constant	3	year	The baseline for reaching maximum liquid biofuel share; based on historical experience, social issues, budgeting system.
Weight toTR pressure effect on land development	Constant	0.2	dimensionless	(1/5) 1 out of 5 variables
Time to progress infrastructure	Constant	1	year	
Fraction of government support	Constant	0.5	dimensionless	(1/2) 1 out of 2 variables
IV infrastructure readiness	Constant	0.2	dimensionless	Estimation (Section 6.5; Appendix C).
IV local government commitment	Constant	0.6	dimensionless	Estimation (Section 6.5; Appendix C).
Time to change local government commitment	Constant	1	year	
IV land certification	Constant	0.2	dimensionless	% certification (EastSumbaLandAgency, 2016)
Time to increase land certification	Constant	1	year	

Parameter	Type	Value	Unit	Notes/Source
IV landowners' respect	Constant	0.9	dimensionless	Estimation (Section 6.5; Appendix C)
Approach to farmers by ethnic elders or association	Constant	1	dimensionless	Estimation (Section 6.5; Appendix C)
Time for private landowners' to understand	Constant	1	dimensionless	Monitoring by the government is annual basis
IV landowners' understanding	Constant	0.5	dimensionless	Estimation (Section 6.5; Appendix C)

Table 7.10 Input variables used in the Sumba marginal land preparedness sub-model

Variable	Sector of origin
Sense of urgency by the President	Policy sub-model
Technical readiness (TR); Year of technology commercially ready.	DBF technology readiness sub-model
Number of non-oilseeds harvest blocks; Total blocks planted; Oil content in seeds; Average oilseeds yield; Time length from cultivation to first harvest.	Sumba feedstock production sub-model
Required oilseeds per DBF plant; Sumba DBF production.	Sumba DBF production from marginal land sub-model

Table 7.11 Output variables from the Sumba marginal land preparedness sub-model

Variable	Sector destination
Year oilseeds ready	Technology readiness sub-model
Marginal land area available for Bioenergy; Actual year of planting start;	Sumba feedstock production sub-model
Desired year of pongamia oil feedstock ready	Sumba DBF production from marginal land sub-model
Actual year of planting start; Marginal land area available for bioenergy.	CO_2 emissions from marginal land use sub-model

7.6.5 Sumba feedstock production sub-model

This sub-model aims to calculate oil feedstock grown on marginal land for DBF production at island level based on the crop growth characteristics. Parameter values which relate to pongamia crop growth properties are estimated based on information from existing research (Murphy et al., 2012). The crop growth is simulated applying a cohort structure to show the pattern of oilseeds production for estimating expected yields based on the expected growth factors of each cohort. The establishment of a blocking system linked to crop rotation cycle is useful in reducing risk investment.

The sub-model is divided into 15 age cohorts, each with a trees stock, an oilseeds yield flow, a growing rate flow, and a planting and growing flow that represents associated year as well as the planted block. The dynamics of tree biomass in each block (TRi), in t) is mathematically represented as:

$$TRi(t) = TRi(0) + \int (r_{Pi} + r_{Gi} - r_{G(i+1)} - r_{Oi})\ dt \qquad \text{Equation 7.24}$$

where i is the age cohort order which shows the end of the annual period of the i^{th} tree's biomass growth; r_{Pi} is planting & growing $(i-1)^{th}$ year to i^{th} year (in t/yr); r_{Gi} is growing $(i-1)^{th}$ year to i^{th} year (in t/yr), and r_{Oi} is oilseeds $(i-1)^{th}$ year to i^{th} year (in t/yr). In non-harvestable blocks, the value of oilseeds ($r_{O(i)}$, in t/yr) is zero.

r_{Pi} and r_{Gi} are calculated as:

$$r_{Pi} = TRi/t_{GR} \qquad \text{Equation 7.25}$$

$$r_{Gi} = TPB * GH_i/t_{GR} \qquad \text{Equation 7.26}$$

where TRi is trees $(i-1)^{th}$ year to i^{th} year (in t); t_{GR} is time to grow (in years) which was taken to be one year; TPB is trees per block (in tree/ha), and GHi is the mass growth of TRi (in t/tree).

Trees per block (TPB, in tree/ha) is determined by trees per ha (TPH) multiplied by planting area per block (PAB, in ha). Hence:

$$TPB = TPH * PAB \qquad \text{Equation 7.27}$$

Planting area per block (PAB, in ha) is calculated as:

$$PAB = \frac{MA(0)}{TBP*BLH} \qquad \text{Equation 7.28}$$

where MA(0) is initial value for marginal land area available for energy crops (ha); total blocks planted (TBP, in block), and blocks harvested (BLH, in blocks).

Sumba oil feedstock for DBF production (OFD, in kl/yr) was calculated as:

$$OFD = OSF * OCS * \frac{kL}{ton} of\ Pongamia\ oil \qquad \text{Equation 7.29}$$

$$OSF = SOH * MFM \qquad \text{Equation 7.30}$$

where OSF is Sumba oilseeds feedstock (in kl/yr); OCS is oil content of seeds (in dimensionless unit); SOH is Sumba oilseeds ready for harvest (in t/yr), and MFM is marginal land feedstock management (in dimensionless unit).

The first harvest of pongamia oilseeds starts after three years of planting. The total oilseeds harvested from the planted blocks are processed to yield pongamia oil as the feedstock for DBF production. The data for growth factors and other properties of pongamia were taken from Chapter 4 and 6.

The marginal land feedstock management includes cultivation of localized feedstocks and feedstock collection, processing, distribution, and cost control. Feedstock management could be optimized through the establishment of a state-owned enterprise (SOE) in agroforestry that integrates both upstream and downstream sides.

Based on Sumba island conditions (Chapter 6), all marginal land for energy crop that are owned by both private landowners and government need to be planted totally at government cost for land preparation up to harvesting, but all the rights up to harvesting belong to farmers. In previous marginal land use programs, when the farmers were not given a full right including for selling and getting revenue from the harvest, they tended not to perform well. In contrast, they did it very well when they had the full rights.

Controlling oilseed costs also minimizes business uncertainty. Oilseeds from private farmers are sold to the SOE by a contract for a certain price over a fixed period. Unlike farmers that cultivate on government land with a full right, private landowners can be given incentives for using their land after a specific period of cultivation or a specific harvesting achievement. The incentive should not be given too early as the Sumba people have shown jealously to their neighbour who has lands that triggered them to do forest burning.

The stock and flow diagram of Sumba feedstock production sub-model is presented in Fig. 7.9.

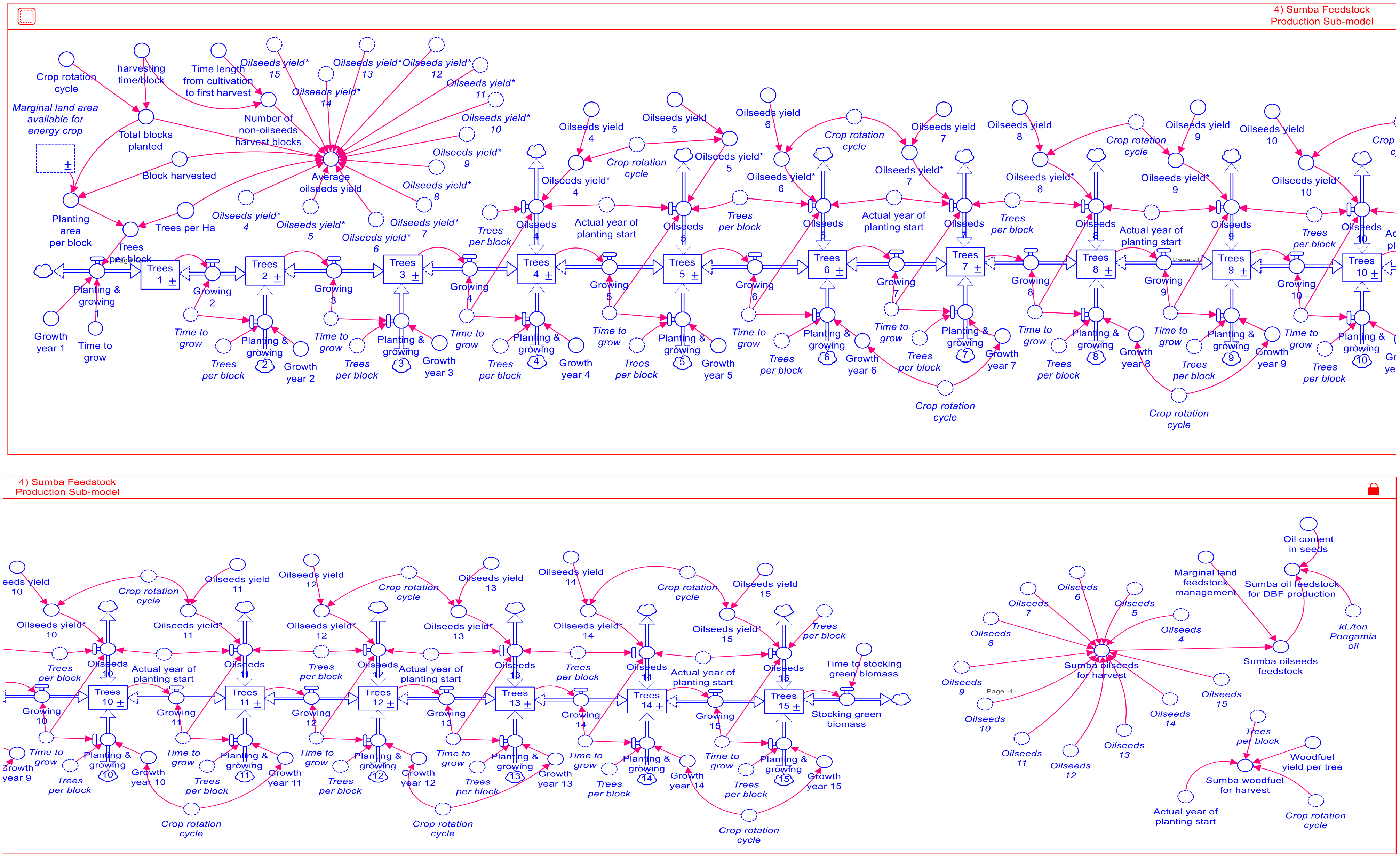


Fig. 7.9 Stock and flow diagram of Sumba feedstock production sub-model

The parameters, input variables and output variables for Sumba feedstock production sub-model are presented in Table 7.12, 7.13 and 7.14, and all the equations for the sub-model are found in Appendix J.

Table 7.12 Parameters used in the Sumba feedstock production sub-model

Parameter	**Type**	**Value**	**Unit**	**Notes/Source**
Trees per ha	constant	350	tree/ha	Murphy et al. (2012)
Crop rotation cycle	constant	15	years	Considering the peak period of pongamia oilseeds harvest at around 8th year.
Block harvested	constant	1	block	
Harvesting time/block	constant	1	year/block	
Time to grow	constant	1	year	
Time length from cultivation to first harvest	Constant	3	year	Murphy et al. (2012)
Growth year 1	constant	0.0005	t/ree	Murphy et al. (2012)
Growth year 2	constant	0.0025	t/ree	Murphy et al. (2012)
Growth year 3	constant	0.017	t/ree	Murphy et al. (2012)
Growth year 4	constant	0.025	t/ree	Murphy et al. (2012)
Growth year 5	constant	0.03	t/ree	Murphy et al. (2012)
Growth year 6	constant	0.02	t/ree	Murphy et al. (2012)
Growth year 7	constant	0.045	t/ree	Murphy et al. (2012)
Growth year 8	constant	0.025	t/ree	Murphy et al. (2012)
Growth year 9	constant	0	t/ree	Murphy et al. (2012)
Growth year 10	constant	0	t/ree	Murphy et al. (2012)
Growth year 11	constant	0	t/ree	Murphy et al. (2012)
Growth year 12	constant	0	t/ree	Murphy et al. (2012)
Growth year 13	constant	0	t/ree	Murphy et al. (2012)
Growth year 14	constant	0	t/ree	Murphy et al. (2012)
Growth year 15	constant	0	t/ree	Murphy et al. (2012)
oilseeds yield 4	constant	0.01	t/ree	Murphy et al. (2012)
oilseeds yield 5	constant	0.01	t/ree	Murphy et al. (2012)
oilseeds yield 6	constant	0.013	t/ree	Murphy et al. (2012)
oilseeds yield 7	constant	0.014	t/ree	Murphy et al. (2012)
oilseeds yield 8	constant	0.025	t/ree	Murphy et al. (2012)
oilseeds yield 9	constant	0.025	t/ree	Murphy et al. (2012)
oilseeds yield 10	constant	0.025	t/ree	Murphy et al. (2012)
oilseeds yield 11	constant	0.025	t/ree	Murphy et al. (2012)
oilseeds yield 12	constant	0.025	t/ree	Murphy et al. (2012)
oilseeds yield 13	constant	0.025	t/ree	Murphy et al. (2012)
oilseeds yield 14	constant	0.025	t/ree	Murphy et al. (2012)
oilseeds yield 15	constant	0.025	t/ree	Murphy et al. (2012)
Oil content in seeds	constant	0.4	dimensionless	Murphy et al. (2012)
Time to stocking green biomass	constant	1	year	Murphy et al. (2012)
Woodfuel yield per tree	constant	0.01	t/tree	Estimation

Parameter	Type	Value	Unit	Notes/Source
Marginal land feedstock management	constant	1	dimensionless	The baseline for maximum oil feedstock production

Table 7.13 Input variables used in the Sumba feedstock production sub-model

Variable name	Sector of origin
Marginal land area available for bioenergy; Actual year of planting start.	Sumba Marginal Land Preparedness Sub-model

Table 7.14 Output variables from the Sumba feedstock production sub-model

Variable name	Sector destination
Number of non-oilseeds harvest blocks; Total blocks planted; Oil content in seeds; Average oilseeds yield; Time length from cultivation to first harvest.	Sumba Marginal Land Preparedness Sub-model
Sumba oil feedstock for DBF production	Sumba DBF Production from Marginal Land sub-model
Sumba oilseeds for harvest; Sumba oil feedstock for DBF production; Sumba woodfuel for harvest.	Economic sub-model
Trees per Ha; Crop rotation cycle; Sumba woodfuel for harvest.	CO_2 emissions from Marginal Land sub-model

7.6.6 Sumba DBF Production from Marginal Land sub-model

This sub-model aims to calculate DBF production from the marginal land-based feedstock at island level, which is required for the estimation at the national level. The structure of DBF production in this sub-model partly adopted the generic structure for commodity market model (Sterman, 2000). This sub-model has three stocks and four flows.

Sumba DBF capacity under construction stock (DU, in kl/yr) is increased by starting DBF construction flow ((r_{SC}, in kl/yr/yr) and decreased by completing DBF construction flow (r_{CC}, in kl/yr/yr); mathematically represented as:

$$DU(t) = DU(0) + \int (r_{SC} - r_{CC})\ dt \qquad \text{Equation 7.31}$$

On the other hand, r_{CC}, (kl/yr/yr) is determined by the Sumba DBF capacity under construction stock (DU, in kl/yr/yr) divided by the DBF plant construction time (t_{CC}, in year). Hence:

$$r_{CC} = \frac{DU}{t_{CC}} \qquad \text{Equation 7.32}$$

Starting DBF construction flow (r_{SC}, in kl/yr/yr) is equal to Sumba added DBF capacity (ADC, in kl/yr/yr) which is represented as:

$$rSC = ADC = \frac{DDC}{t_{AC}} - RDC \quad \text{Equation 7.33}$$

$$DDC = OFD \quad \text{Equation 7.34}$$

where DDC is Sumba desired DBF capacity (kl/yr); t_{AC} is time to adjust capacity (years); RDC is Sumba's remaining DBF capacity (kl/yr), and OFD is Sumba's oil feedstock for DBF production (kl/yr).

Sumba DBF production capacity stock (DP, in kl/yr) is increased by completing DBF construction flow (r_{CC}, in kl/yr/yr) and decreased by discarding DBF capacity flow (r_{IC}, in kl/yr). Thus:

$$DP(t) = DP(0) + \int (r_{CC} - r_{IC})\ dt \quad \text{Equation 7.35}$$

$$r_{IC} = DP/t_{DL} \quad \text{Equation 7.36}$$

where t_{DL} is DBF capacity life time.

The key flow, Sumba DBF production (r_{DP}, in kl/yr) is calculated as:

$$r_{DP} = MIN(DP, OFD * OFL) \quad \text{Equation 7.37}$$

where OFD is Sumba oil feedstock for DBF production (kl/yr), and OFL is oil feedstock conversion (dimensionless).

Sumba DBF accumulated production (AP, in kl) is determined by Sumba DBF production (r_{DP}, in kl/yr) and represented as:

$$AP(t) = AP(0) + \int (r_{DP})\ dt \quad \text{Equation 7.38}$$

The stock and flow diagram of DBF production from the marginal land sub-model is presented in Fig. 7.10.

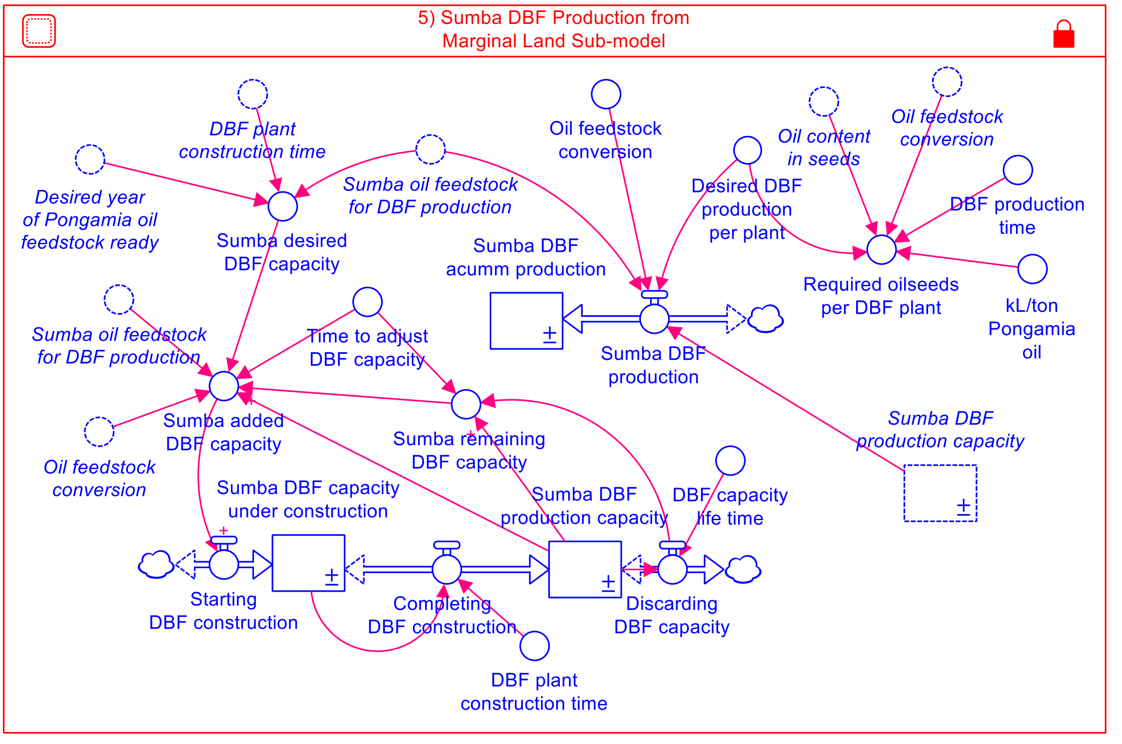


Fig. 7.10 Stock and flow diagram of Sumba DBF production from marginal land sub-model

The parameters, input variables and output variables for the Sumba DBF production from the Marginal Land sub-model are presented in Table 7.15, 7.16 and 7.17, and all the equations for the sub-model are found in Appendix J.

Table 7.15 Parameters used in the Sumba DBF Production from marginal land sub-model

Parameter	**Type**	**Value**	**Unit**	**Notes/Source**
DBF plant construction time	constant	2	year	Common practice of similar oleochemical plants
DBF capacity life time	constant	20	year	
Time to adjust DBF capacity	constant	1	year	
Oil feedstock conversion	constant	0.76	dimensionless	Table 5.1
Desired DBF production per plant	constant	50,000	kl/yr	Soerawidjaja (2016a)
DBF production time	constant	1	year	

Table 7.16 Input variables used in the Sumba DBF Production from marginal land sub-model

Variable name	**Sector of origin**
Desired year of pongamia oil feedstock ready; Desired DBF production per plant.	Sumba Marginal Land Preparedness Sub-model
Oil content in seeds; Sumba oil feedstock for DBF production	Sumba Feedstock Production Sub-model

Table 7.17 Output variables from the DBF Production from marginal land sub-model

Variable name	**Sector destination**
Required oilseeds per DBF plant; Sumba DBF production.	Sumba Marginal Land Preparedness Sub-model
Sumba DBF production	Sumba DBF supply-demand sub-model; Liquid Biofuel transition sub-model; Economic sub-model; CO_2 emissions from Marginal Land Use sub-model.

7.6.7 Sumba DBF supply and demand sub-model

This sub-model aimed to calculate Sumba liquid fuel self-sufficiency through DBF production and use, which is a very important indicator since Sumba island has no crude oil resources for supplying the liquid fuel demand (Chapter 6).

Sumba DBF supply (r_{DS}, in kl/yr) and Sumba DBF consumption (r_{DC}, in kl/yr) determine the dynamics of Sumba DBF stock (DT, in kl). Hence:

$$DT(t) = DT(0) + \int (r_{DS} - r_{DC})\ dt \qquad \text{Equation 7.39}$$

Sumba DBF supply (r_{DS}, in kl/yr) is determined by Sumba DBF for export (SDE in kl/yr) subtracted from Sumba DBF production (r_{DP}, in kl/yr). Thus:

$$r_{DS} = r_{DP} - SDE \qquad \text{Equation 7.40}$$

Determination of Sumba DBF consumption (r_{DC}, in kl/yr) depends on whether Sumba liquid fuel demand (SLD, in kl/yr) is larger than Sumba DBF production (r_{DP}, in kl/yr) or not. If yes, r_{DC} is equal to Sumba liquid fuel demand (SLD, in kl/yr). otherwise, it is determined by Sumba DBF stock (DT, in kl) divided by time to average Sumba DBF stock (t_{DT}, in year). Thus:

$$r_{DC} = DT/t_{DT} \qquad \text{Equation 7.41}$$

Sumba liquid fuel self-sufficiency (SLF, in dimensionless unit) is calculated as:

$$SLF = \frac{SLD - SLI}{SLD} \qquad \text{Equation 7.42}$$

$$SLI = SLD - r_{DP} \qquad \text{Equation 7.43}$$

where SLD is Sumba liquid fuel demand (kl/yr); SLI is Sumba liquid fuel import demand (kl/yr), and r_{DP} is Sumba DBF production (kl/yr).

The stock and flow diagram of Sumba DBF supply and demand sub-model is presented in Fig. 7.11.

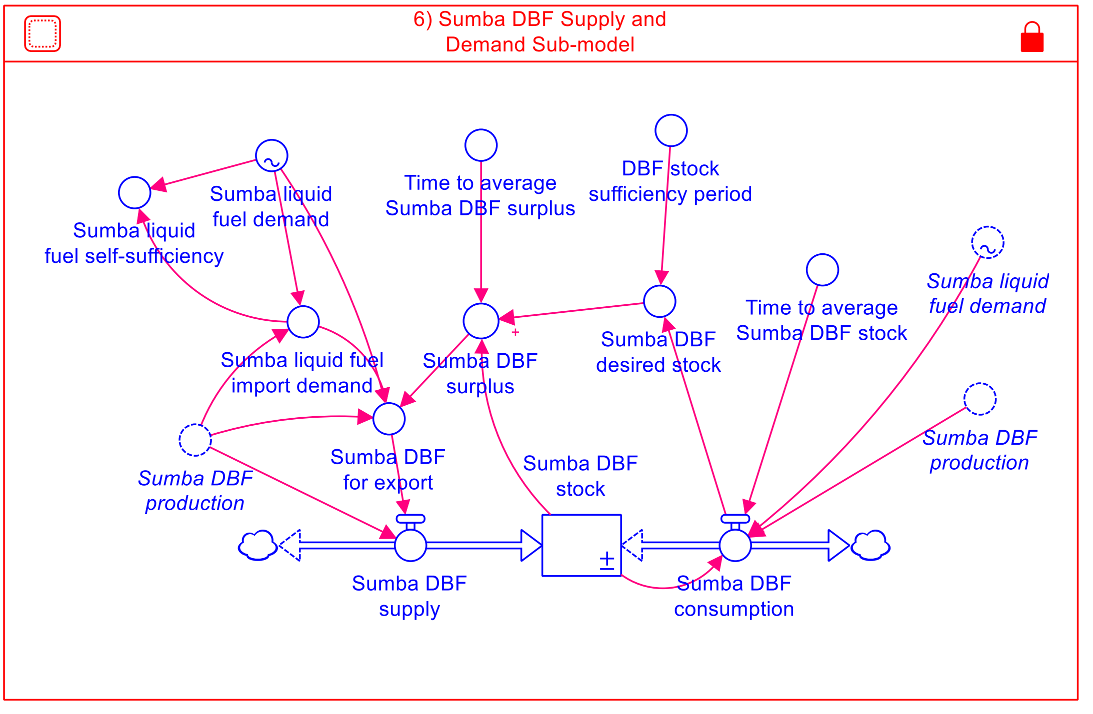


Fig. 7.11 Stock and flow diagram of Sumba DBF supply and demand sub-model

The parameters, input variables and output variables for the Sumba DBF supply and demand sub-model are presented in Table 7.18, 7.19 and 7.20, and all the equations for the sub-model are found in Appendix J.

Table 7.18 Parameters used in the Sumba DBF supply and demand sub-model

Parameter	Type	Value	Unit	Notes/Source
Time to average Sumba DBF surplus	Constant	1	year	
DBF stock sufficiency period	Constant	1/12	year	estimation
Time to average Sumba DBF stock	Constant	1	year	
Sumba liquid fuel demand	Time series		kl/yr	2018-2025: TSIID (2012); 2025-2045: assumed 5% growth

Table 7.19 Input variables used in the Sumba DBF supply and demand sub-model

Variable name	Sector of origin
Sumba DBF production	Sumba DBF Production from Marginal Land Sub-model

Table 7.20 Output variables from the Sumba DBF supply and demand sub-model

Variable name	Sector destination
Sumba DBF self-consumption	CO_2 Emissions from Marginal Land Use Sub-model

7.6.8 Liquid biofuel transition sub-model

Based on the expected time for preparedness of the DBF production technology and the feedstock from marginal land (Section 7.6.4 – 7.6.6), it is likely that pongamia oil feedstock from marginal land will have not been available by the time DBF commercial production starts. Therefore, it will use palm oil which has also been the feedstock for biodiesel, the existing liquid biofuel. Palm oil has been the main feedstock in the R&D of DBF production technology (Chapter 5).

In assessing to what extent liquid biofuel can fill the national liquid fuel demand, it is necessary to know how palm oil DBF increases while palm oil biodiesel decrease when DBF commercial production starts. This sub-model assesses the dynamics of transition from palm biodiesel production to palm DBF production in order to estimate the dynamics of transition from biodiesel production to national total production of DBF.

This sub-model grouped the stocks and flows into palm oil, biodiesel, and DBF. It has two important feedback loops: (i) between national DBF production and biodiesel production and (ii) between palm oil consumption for biodiesel and DBF and palm oil for DBF.

In this study palm oil refers to oil extracted from palm fruit shell, consisting of crude palm oil (CPO) and refined forms of palm oil, so it excludes palm kernel oil which is produced from oil palm seeds. By the time of DBF readiness, only biodiesel from CPO is available as the oxygenated biofuel (Section 2.3).

CPO average productivity (CA, in t/ha) is represented as:

$$CP(t) = CP(0) + \int r_{CP} \ dt \qquad \text{Equation 7.44}$$

$$r_{CP} = CPT/t_{CP} \qquad \text{Equation 7.45}$$

where r_{CP} is CPO productivity increase rate (in t/ha/yr); CPT is CPO productivity increase target (in t/ha), and t_{CP} is expected time to increase CPO productivity (years).

Palm oil supply for biodiesel and DBF (r_{PS}, in t/yr) and palm oil consumption for biodiesel and DBF (r_{PC}, in t/yr) determined the palm oil feedstock for biodiesel and DBF (PT, in t/yr), and represented as:

$$PT(t) = PT(0) + \int (r_{PS} - r_{PC}) \ dt \qquad \text{Equation 7.46}$$

Palm oil supply for biodiesel & DBF (r_{PS}, in t/yr) is calculated as:

$$r_{PS} = POP - PFO - PFE - PAD \qquad \text{Equation 7.47}$$

where POP is palm oil production (t/yr); PFE is palm oil for export (t/yr); PFO is palm oil consumed for food and oleo non-biodiesel (t/yr), and PAD is palm oil available for DBF (t/yr). After DBF technology is commercially ready, palm oil export (PFE, t/yr) is limited by setting domestic market obligations (DMO).

Palm oil available for DBF (PAD, in t/yr) is equal to palm oil stock surplus (POS, in t/yr) which is the difference between palm oil stock for biodiesel and DBF (PT, in t/yr) and palm oil desired stock for biodiesel and DBF (t/yr). Thus:

$$PAD = POS \qquad \text{Equation 7.48}$$

Palm oil consumption for biodiesel and DBF (r_{PC}, in t/yr) is determined by palm oil stock for biodiesel & DBF (PT, in t/yr) divided by time averaging palm oil consumption for DBF (t_{CB}, in years). Hence:

$$r_{PC} = PT/t_{CB} \qquad \text{Equation 7.49}$$

Palm oil available for DBF (PAD, in t/yr) and palm oil consumption for biodiesel & DBF (r_{PC}, in t/yr) involve in an important feedback loop.

The dynamics of biodiesel capacity under construction (BU, in kl/yr) is represented as:

$$BU(T) = BU(0) + \int (r_{SB} - r_{CB})\ dt \qquad \text{Equation 7.50}$$

$$r_{SB} = ABC \qquad \text{Equation 7.51}$$

$$r_{CB} = BU/t_{BR} \qquad \text{Equation 7.52}$$

where r_{SB} = start of biodiesel construction (kl/yr/yr); r_{CB}= completing biodiesel construction (kl/yr/yr); ABC is added biodiesel capacity (ABC, in kl/yr/yr), and t_{BR} is biodiesel plant construction time (in year).

Added biodiesel capacity (kl/yr) is calculated as:

$$ABC = Max\left[0, \left(\frac{DBC}{t_{AB}} - RBC\right)\right] \qquad \text{Equation 7.53}$$

where t_{AB} is time to adjust biodiesel capacity (years), DBC is desired biodiesel capacity (kl/yr), and RBC is remaining biodiesel capacity (kl/yr/yr).

Desired biodiesel capacity (kl/yr) is equal to the biodiesel existing mandate (BEM, in kl/yr) under the condition that the national DBF production has not been realised. Otherwise, it is calculated as:

$$DBC = DCB * NDT \qquad \text{Equation 7.54}$$

where DCB is concentration of diesel combustion booster (in dimensionless unit), and NDT is national DBF production (kl/yr). DCB is concentration of cetane booster in diesel fuel which is expected to be added as biodiesel up to 30% of DBF (Soerawidjaja, 2018a). Therefore, in DBF era, palm biodiesel keeps being produced and used at less rate.

Remaining biodiesel capacity (RBC, in kl/yr/yr) is represented as:

$$RBC = \frac{BP}{t_{AB}} - r_{IB} \qquad \text{Equation 7.55}$$

where BP is biodiesel production capacity (kl/yr), t_{AB} is time to adjust biodiesel capacity (years), and r_{IB} is discarding biodiesel capacity (kl/yr/yr).

Biodiesel production capacity (BP, in kl/yr) is mathematically represented as:

$$BP(t) = BP(0) + \int (r_{CB} - r_{IB})\, dt \qquad \text{Equation 7.56}$$

where r_{CB} is completing biodiesel capacity (kl/yr), and r_{IB} is discarding biodiesel capacity (kl/yr). Biodiesel production capacity in 2018 (BP(0)) was assumed to be 6.5 Gl/yr or the same as the actual biodiesel production, although the installed capacity was 11 Gl/yr which the detail condition are unknown.

Discarding biodiesel capacity (r_{IB}, in kl/yr) is calculated as:

$$r_{IB} = BP/t_{BL} \qquad \text{Equation 7.57}$$

where t_{BL} is biodiesel capacity life time (years).

Biodiesel supply (r_{BY}, in kl/yr) and biodiesel consumption (r_{BM}, in kl/yr) determine the dynamics of biodiesel stock (BK, in kl), and mathematically represented as:

$$BK(t) = BK(0) + \int (r_{BY} - r_{BM})\, dt \qquad \text{Equation 7.57}$$

$$r_{BY} = BDP - BEQ \qquad \text{Equation 7.58}$$

$$r_{BM} = BK/t_{BM} \qquad \text{Equation 7.59}$$

where r_{BY} is biodiesel supply (kl/yr); r_{BM} is biodiesel consumption (kl/yr); BDP is biodiesel production (kl/yr); BEQ is biodiesel export quota (kl/yr), and t_{BM} is time averaging biodiesel consumption (t_{BM}, in years).

For easier understanding of the model, the running capacity of the biodiesel plant was assumed to be the same as the functional capacity. Hence, biodiesel production (BDP, in kl/yr) is equal to biodiesel production capacity (BP, in kl/yr). Thus:

$$BDP = BP \qquad \text{Equation 7.60}$$

Another important feedback loop in this sub-model involves biodiesel production (BDP, in kl/yr) and DBF production from palm oil (DPP, in kl/yr).

DBF production from palm oil (DPP, in kl/yr) is calculated as:

$$DPP = \left(PAD + (r_{PC} - PDB)\right) * \frac{kL}{ton} of\ palm\ oil \qquad \text{Equation 7.61}$$

where PAD is palm oil available for DBF (t/yr), r_{PC} is palm oil consumption for biodiesel & DBF (t/yr), and PDB is palm oil demand for biodiesel (t/yr).

National DBF production (NDT, in kl/yr) is the sum of National DBF production from marginal land (NDM, in kl/yr) and DBF production from palm oil (DPP, in kl/yr). Hence:

$$NDT = NDM + DPP \qquad \text{Equation 7.62}$$

National DBF production from marginal land (NDM, in kl/yr) is calculated by multiplying Sumba DBF production (r_{DP}, in kl/yr) and the DBF multiplier to go from Sumba level to the national level (NSM, in dimensionless unit). Thus:

$$NDM = r_{DP} * NSM \qquad \text{Equation 7.63}$$

The stock and flow diagram of liquid biofuel transition sub-model is presented in Fig. 7.12.

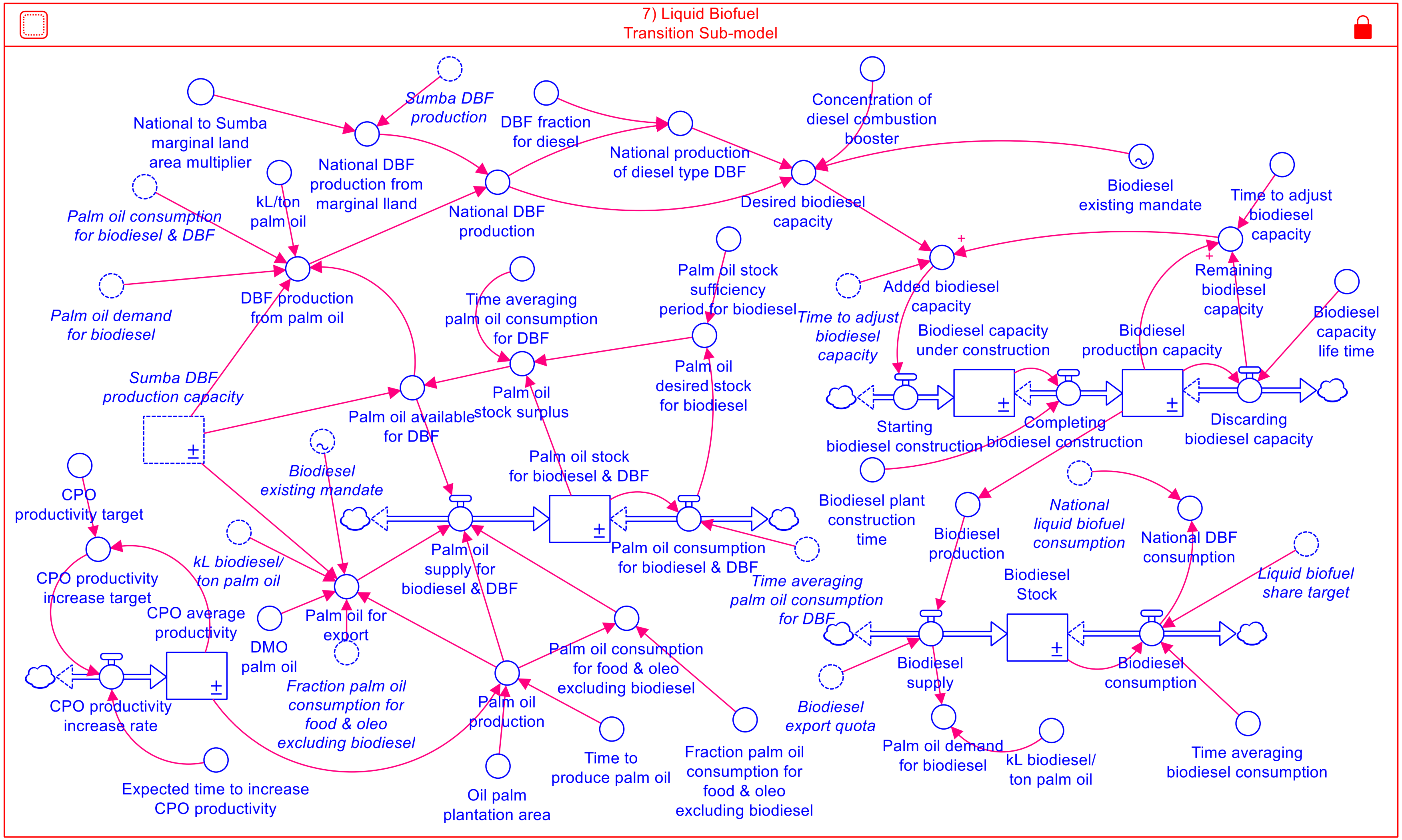


Fig. 7.12 Stock and flow diagram of liquid biofuel transition sub-model

The parameters, input variables and output variables for liquid biofuel transition sub-model are presented in Table 7.21, 7.22 and 7.23, and all the equations for the sub-model are found in Appendix J.

Table 7.21 Parameters used in liquid biofuel transition sub-model

Parameter	Type	Value	Unit	Notes/Source
CPO productivity target	constant	5	t/ha	GAPKI (2018)
Initial value (IV) for CPO average productivity	constant	3	t/ha	GAPKI (2018)
Expected time to increase CPO productivity	constant	27	year	Stop time-start time
Oil palm plantation area	constant	14 million	ha	GAPKI (2018)
Time to produce palm oil	constant	1	year	
Fraction palm oil consumption for food & oleo excluding biodiesel	constant	0.1		current trend
DMO palm oil	constant	0.9	dimensionless	assumption
Palm oil stock sufficiency period for biodiesel	constant	1/12	year	
Time averaging palm oil consumption for DBF	constant	1	year	
Biodiesel existing mandate	time series		kl/yr	MEMR (2015)
Concentration of diesel combustion booster	constant	0.2	dimensionless	(Soerawidjaja, 2018a)
DBF fraction for diesel	constant	0.4	dimensionless	Historical statistics
IV of biodiesel stock	constant	0	kl	Estimation
Time to adjust biodiesel capacity	constant	1	years	
Biodiesel plant construction time	constant	2	years	
Biodiesel capacity life time	constant	20	Years	

Parameter	Type	Value	Unit	Notes/Source
IV of biodiesel capacity under construction	constant	0	kl/yr	
IV of biodiesel production capacity	constant	6.5 million	kl/yr	Assumed = biodiesel production at start time
Time averaging biodiesel consumption	constant	1	years	
National to Sumba marginal land area multiplier	constant	50	dimensionless	estimation

Table 7.22 Input variables used in liquid biofuel transition sub-model

Variable name	Module of origin
Sumba DBF production	Sumba DBF production from marginal land sub-model
National liquid biofuel consumption; Biodiesel export quota.	National Liquid Biofuel Supply and Demand Sub-model

Table 7.23 Output variables from the liquid biofuel transition sub-model

Variable name	Module destination
National biodiesel consumption; Biodiesel export quota; National DBF production.	Policy sub-model
National biodiesel supply; National DBF production; Biodiesel export quota.	National Liquid Biofuel Supply and Demand Sub-model
DBF production from palm oil; National DBF consumption; National biodiesel accumulated consumption.	Economic sub-model
National to Sumba marginal land area multiplier	CO_2 emissions from Marginal Land Use sub-model

7.6.9 National liquid biofuel supply and demand sub-model

This sub-model aims to simulate national liquid biofuel supply and demand through DBF implementation. This sub-model consists of national liquid biofuel stocks, national liquid biofuel supply flows, and national liquid biofuel for consumption flow. These variables are used in the calculation of national liquid fuel self-sufficiency and the actual share of national liquid biofuels which are the model's main indicators.

National liquid biofuel supply (r_{BS}, in kl/yr) and national liquid biofuel for consumption (r_{BC}, in kl/yr) determine national liquid biofuel stock (BT, in kl). Thus:

$$BT(t) = BT(0) + \int (r_{BS} - r_{BC})\ dt \qquad \text{Equation 7.64}$$

$$r_{BS} = NBP - NBE \qquad \text{Equation 7.65}$$

where NBP is national liquid biofuel production (kl/yr) and NBE is national liquid biofuel for export (kl/yr).

If national liquid biofuel production (kl/yr) does not exceed the national liquid fuel demand (NLD, in kl/yr), then national liquid biofuel for consumption (r_{BC}, in kl/yr) is equal to the national liquid fuel demand (NLD, in kl/yr). Otherwise, it is calculated as:

$$r_{BC} = BT/tBC \qquad \text{Equation 7.66}$$

where BT is national liquid biofuel stock (BT, in kl), and t_{BC} is time to average national liquid biofuel for consumption (years).

National liquid fuel self-sufficiency (NLF, in dimensionless unit) is calculated as:

$$NLF = (NLD - NLI)/NLD \qquad \text{Equation 7.77}$$

$$NLI = NLD - (NOP + NBP) \qquad \text{Equation 7.78}$$

where NLD is national liquid fuel demand (kl/yr); NLI is national liquid fuel import demand (kl/yr); NOP is national oil fuels production (kl/yr), and NBP is national liquid biofuel production (kl/yr).

National liquid biofuel actual share (BSA, in dimensionless unit) is determined as the ratio of national liquid biofuel consumption (NBC in kl/yr) to national liquid fuel demand (NLD, in kl/yr). Hence:

$$BSA = NBC/NLD \qquad \text{Equation 7.79}$$

National liquid biofuel consumption (NBC in kl/yr) is mathematically represented as:

$$NBC = MIN(r_{BC}, BST * NLD) \qquad \text{Equation 7.80}$$

where r_{BC} is national liquid biofuel for consumption (kl/yr), BST is national liquid biofuel share target (in dimensionless unit), and NLD is national liquid fuel demand (kl/yr).

The stock and flow diagram of national liquid biofuel supply and demand sub-model is presented in Fig. 7.13.

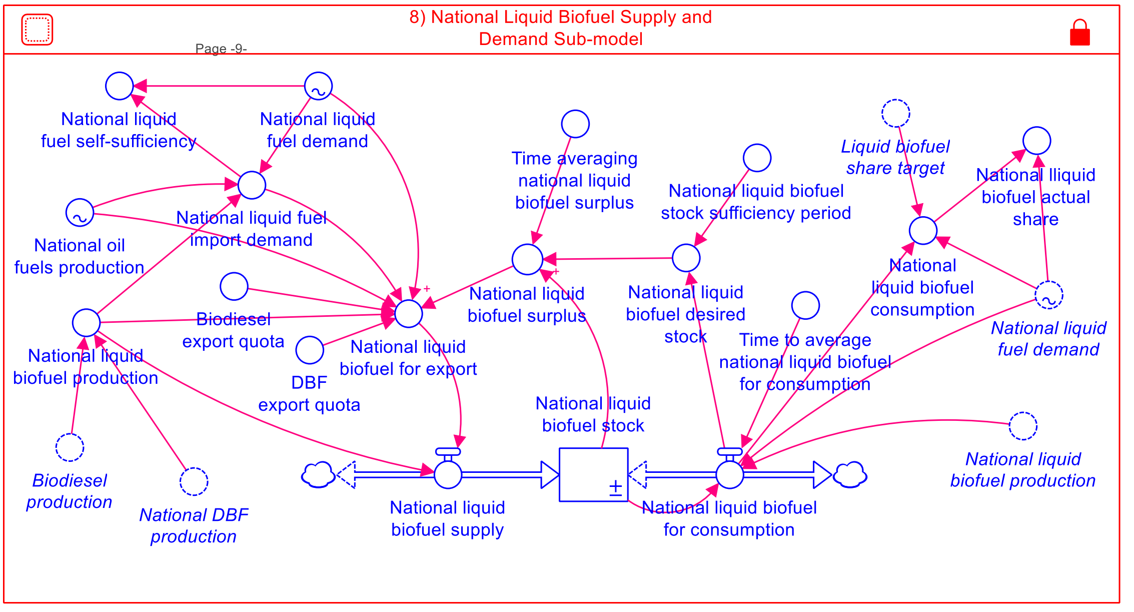


Fig. 7.13 Stock and flow diagram of national liquid biofuel supply and demand sub-model

The parameters, input variables and output variables for the national liquid biofuel supply and demand sub-model are presented in Table 7.24, 7.25 and 7.26, and all the equations for the sub-model are found in Appendix J.

Table 7.24 Parameters used in the national liquid biofuel supply and demand sub-model

Parameter	**Type**	**Value**	**Unit**	**Notes/Source**
National liquid fuel demand	Time series		kl/yr	BPPT (2018)
National oil fuels production	Time series		kl/yr	BPPT (2018)
Time averaging national liquid biofuel surplus	Constant	1	years	
National liquid biofuel stock sufficiency period	Constant	1/12	years	assumption
Biodiesel export quota	Constant	1 million	kl/yr	assumption
DBF export quota	Constant	1 million	kl/yr	assumption

Table 7.25 Input variables used in the national liquid biofuel supply and demand sub-model

Variable name	**Sector of origin**
Liquid biofuel share target	Policy sub-model
National biodiesel supply; National DBF production.	Liquid Biofuel Transition sub-model

Table 7.26 Output variables from the national liquid biofuel supply and demand sub-model

Variable name	**Sector destination**
National DBF consumption	Policy sub-model

7.6.10 Economic sub-model

The feedstock cost dominates the biofuel production cost. It can be managed, *among other things*, by a strong government role to maintain the commitment of land use for energy crop purposes, especially for the marginal lands that are owned by the government. An economic simulation at the island level is necessary as every island has different characteristics in the program implementation.

This sub-model aims to calculate the potential economic benefits from DBF implementation using the indicators of an increase in gross regional domestic product (GRDP) at the local level and foreign exchange saving at the national level. The data and information for building the sub-model were taken from a focus group discussion, secondary literature, and results from other sub-models.

The key variable in this sub-model is pongamia oil feedstock cost (FC, in IDR/L) stock which is influenced by changes in oil feedstock cost (r_{FC}, in IDR/yr) flows. On the other hand, changes in oil feedstock cost is influenced by pongamia oil feedstock cost and pongamia oil feedstock cost growth rate (FCG, in dimensionless unit/yr). Thus:

$$FC = FC(0) + \int r_{FC}\ dt \qquad \text{Equation 7.81}$$

$$r_{FC} = FC * FCG \qquad \text{Equation 7.82}$$

Pongamia oil feedstock cost is used for calculating pongamia DBF production cost (FDC, in IDR/L) which is represented as:

$$FDC = (FC + DCC * IDR/USD - BPR) \qquad \text{Equation 7.83}$$

where DCC is DBF conversion cost (USD/L) which was adopted from a study of DBF production through hydrodeoxygenation process oversea (Pearlson et al., 2013), and BPR is by-product revenues (IDR/L). The type of DBF technology simulated in the model applies the metal soap decarboxylation process which the production cost of any scale is similar (Chapter 5, (Soerawidjaja, 2016a)).

The economic indicator at the national level is foreign exchange saving (FES, in USD/yr) which is calculated as:

$$FES = NDN * DBP + r_{BM} * BIP \qquad \text{Equation 7.84}$$

where NDN is national DBF consumption (kl/yr), DBP is DBF price (in USD/kl), r_{BM} is biodiesel consumption (kl/yr), and BIP is biodiesel price (in USD/kl).

The economic indicator at local level is Sumba GRDP increase from DBF, oilseeds, and woodfuel (SGI, in USD/yr) which is calculated as:

$$SGI = r_{DC} * \frac{DBP}{IDR/USD} * L/kL + SOH * OSP + \frac{SWH}{WCT} * WFP \qquad \text{Equation 7.85}$$

where r_{DC} is Sumba DBF production (kl/yr), DBP is DBF price (USD/kl), SOH is Sumba oilseeds for harvest (t/yr), OSP is oilseeds price (USD/t), SWH is Sumba woodfuel for harvest (t/yr), WCT is woodfuel consumption time (years), and WFP is woodfuel price (USD/t).

DBF price (DBP, in USD/kl) is calculated as:

$$DBP = \frac{(FDC*NDM+DPO*PDC)*(1+DBM))}{NDM*DBP} \qquad \text{Equation 7.86}$$

where FDC is pongamia DBF production cost (IDR/L), NDM is national DBF production from marginal land (kl/yr), DPO is DBF production from palm oil (kl/yr), PDC is palm DBF production cost (IDR/L), and DPM is DBF profit margin (dimensionless unit).

Biodiesel price (BIP, in USD/kl) is the sum of CPO price (CPP, in USD/t) and biodiesel converting cost (BCC, in USD/t). Hence:

$$BIP = (CPP + BCC)/\frac{kL}{ton}\, of\ palm\ oil \qquad \text{Equation 7.87}$$

The stock and flow diagram of the economic sub-model is presented in Fig. 7.14.

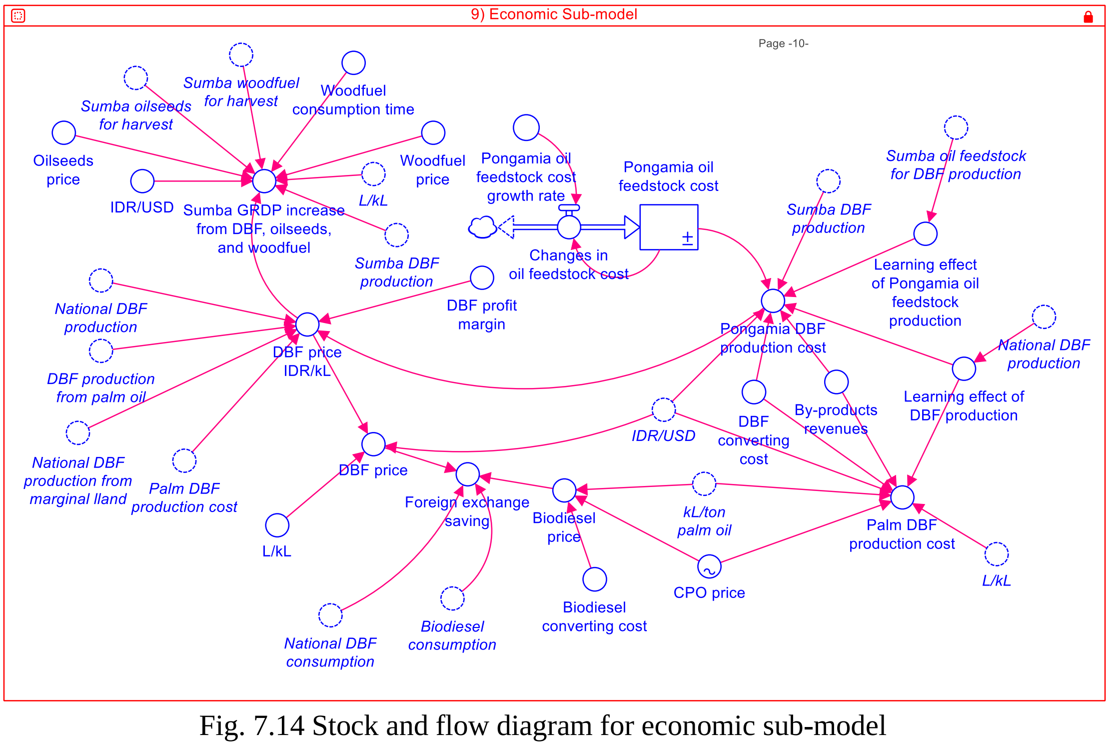


Fig. 7.14 Stock and flow diagram for economic sub-model

The parameters, input variables and output variables for the economic sub-model are presented in Table 7.27, 7.28 and 7.29, and all the equations for the sub-model are found in Appendix J.

Table 7.27 Parameters used in economic sub-model

Parameter	Type	Value	Unit	Notes/Source
Oilseeds price	constant	15	USD/t	Murphy et al. (2012)
Woodfuel consumption time	constant	1	years	
Woodfuel price	constant	50	USD/t	assumption
DBF profit margin	constant	0.1	dimensionless	common practice
DBF conversion cost	constant	0.36	USD/L	Pearlson et al. (2013)
Biodiesel conversion cost	constant	100	USD/t	MEMR (2016b)
Initial value (IV) for pongamia oil feedstock cost	constant	5,000	IDR/l	Murphy et al. (2012)
By-products revenues	constant	1,000	IDR/l	estimation for seed cake revenue
Pongamia oil feedstock cost growth rate	constant	0.001	dimensionless	Estimation. Well controlled by government.
Learning effect of pongamia oil feedstock production	constant	1	dimensionless	The oil feedstock cost was adopted from Murphy et al. (2012) through interpolation
CPO price	Time series		USD/t	Future projection of IndexMundi (2019b) to increase gradually

Table 7.28 Input variables used in economic sub-model

Variable name	Sector of origin
Sumba oilseeds for harvest; Sumba oil feedstock for DBF production; Sumba woodfuel for harvest.	Sumba Feedstock Production sub-model
DBF production from palm oil; National DBF production; National DBF production from marginal land; National biodiesel consumption.	Liquid Biofuel Transition sub-model
Sumba DBF production	Sumba DBF Production from Marginal Land sub-model

Table 7.29 Output variables from economic sub-model

Variable	Destination
DBF price; Biodiesel price.	Policy sub-model

7.6.11 CO_2 emissions from marginal land use sub-model

This last sub-model consists of Sumba accumulated CO_2 emissions stock and Sumba CO_2 emissions flow. The CO_2 emissions calculations cover land use and energy use, using inputs from previous sub-models such as the marginal land area available for energy crop, actual year of planting start, crop rotation cycle, Sumba DBF production, Sumba DBF consumption, and Sumba woodfuel for harvest. Sumba CO_2 emissions is determined for estimating national CO_2 emissions in calculating the potential contribution to the Indonesian Nationally Determined Contribution (NDC) to the Paris Climate Agreement (Chapter 2).

Sumba accumulated CO_2 emissions (CA, t CO_2e) is determined by Sumba CO_2 emission (r_{CE}, in t CO_2e/yr). Sumba CO_2 emission is calculated by summing up net CO_2 emissions from marginal land carbon stock (CEM, in t CO_2e/yr), net CO_2 emission from DBF (CED, in t CO_2e/yr), and net CO_2 emission from bioelectricity (CEL, t CO_2e/yr). (Equation 7.89). Thus:

$$CA = CA(0) + \int r_{CA} \; dt \qquad \text{Equation 7.88}$$

$$r_{CE} = CEM + CED + CEL \qquad \text{Equation 7.89}$$

where CEM is CO_2 emissions from marginal land carbon stock (t CO_2e/yr), CED is net CO_2 emissions from DBF (t CO_2e/yr), and CEL is net CO_2 emissions from bioelectricity (t CO_2e/yr). CEM, CED and CEL are calculated using equations 7.90 up to 7.92.

Calculation of CO_2 emissions from marginal land carbon stock (CEM, t CO_2e/yr) applied “stock difference” approach and the concept of time-averaged carbon stock. The data activity is based on carbon stock difference between the initial coverage and the on-going coverage. The net emission is equal to half of the emission at the end of the first cycle, as the net emissions in the following cycles are equal to zero. (Santosa et al. (2014); US-EPA (2012))

CO_2 emissions from marginal land carbon stock (CEM, t CO_2e/yr) is mathematically represented as:

$$CEM = \left\lfloor (CTO - CST * TPH) * \frac{MAE(0)}{CRC} * (time - AYP)/CRC \right\rfloor \qquad \text{Equation 7.90}$$

where CTO is C stock open land (t CO_2e/yr), CST is CO_2e sequestrated per tree (t CO_2e/tree), TPH is trees per ha (tree/ha), MA(0) is the initial value for marginal land area available for energy crop (ha), CRC is crop rotation cycle (years), and AYP is actual year of planting start (years).

Net CO_2 emissions from DBF (CED, in t CO_2e/yr) is calculated by substracting avoided CO_2 emission from DBF consumption (ACD, in t CO_2e/yr) from CO_2 emissions from DBF production (CDP, in t CO_2e/yr), and represented as:

$$CED = CDP - ACD \quad \text{Equation 7.91}$$

Net CO_2 emission from bioelectricity generation (CEL, t CO_2e/yr) is calculated by substracting woodfuel CO_2 emission from bioelectricity generation (CWL, t CO_2e/yr) from avoided CO_2 emissions from diesel electricity generation (ACL, t CO_2e/yr). Thus:

$$CEL = CWL - ACL \quad \text{Equation 7.92}$$

In estimating national accumulated CO_2 emission (NCA, t CO_2e/yr) and national CO_2 emissions (NCE, t CO_2e/yr), a multiplying factor was set to cover the area expansion from the local to national level. The national accumulated CO_2 emission is determined by multiplying Sumba accumulated CO_2 emissions (CA, in t CO_2e) with the multiplier for national to Sumba marginal land area (NSM, in dimensionless unit). Thus:

$$NCA = CA * NSM \quad \text{Equation 7.93}$$

Similarly, national CO_2 emission (NCE, t CO_2e/yr) is estimated by multiplying Sumba CO_2 emission flow (r_{CE}, t CO_2e/yr) with the multiplier for national to Sumba marginal land area m (NSM, in dimensionless unit). Hence:

$$NCE = r_{CE} * NSM \quad \text{Equation 7.94}$$

Establishment of a state-owned bioenergy enterprise in agroforestry that integrates upstream and downstream can support the achievement of CO_2 emission reduction through growing biomass feedstock on marginal land.

The stock and flow diagram of CO_2 emissions from marginal land sub-model is presented in Fig. 7.15.

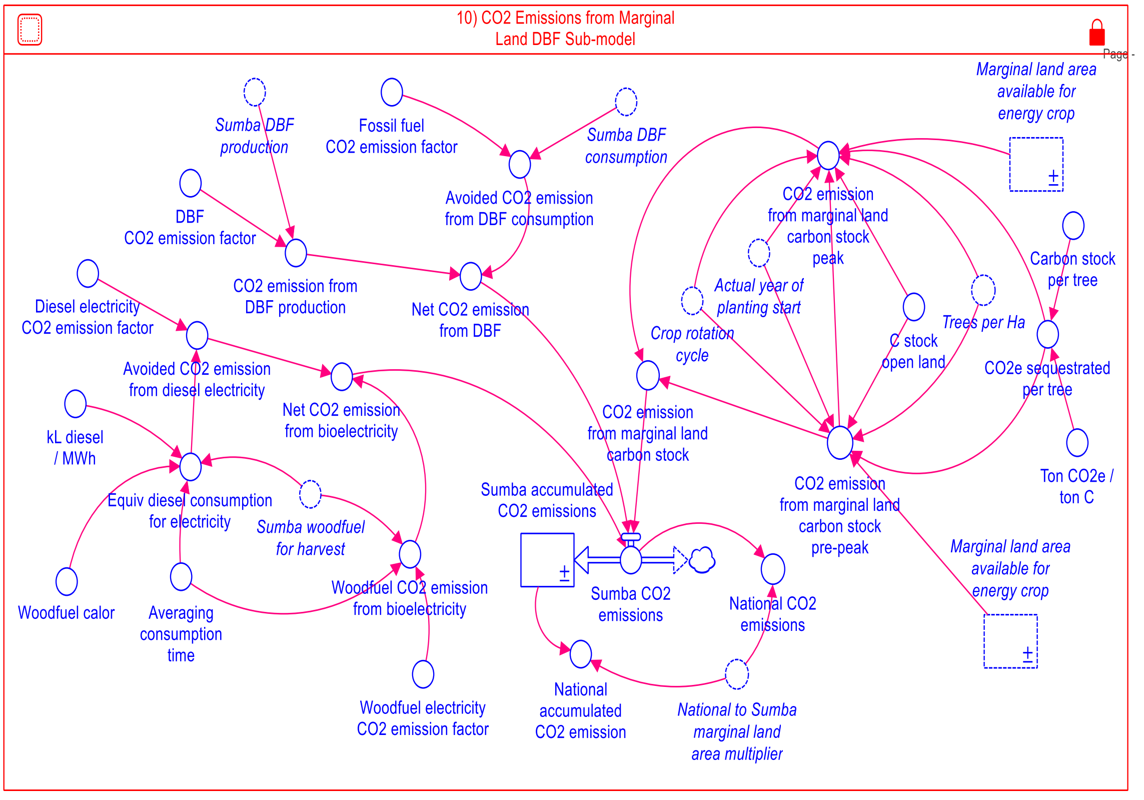


Fig. 7.15 Stock and flow diagram of CO_2 emissions from marginal land use sub-model

The parameters and input variables for the CO_2 emissions from marginal land use sub-model are presented in Table 7.30, and 7.31 and all the equations for the sub-model are found in Appendix J.

Table 7.30 Parameters used in the CO_2 emissions from marginal land use sub-model

Parameter	**Type**	**Value**	**Unit**	**Notes/Source**
Carbon stock on open land	Constant	2.5	t CO_2e/ha	Santosa et al. (2014)
Carbon stock per tree	Constant	0.25	t C / tree	Murphy et al. (2012)
DBF CO_2 emission factor	Constant	0.5	t CO_2e/kl	Estimation; Hartono and Irsyad (2011) Assumption = biodiesel for electricity
Fossil fuel CO_2 emission factor	Constant	2.8	t CO_2e/kl	Estimation; MEMR (2016a); Assumption = average petroleum fuels
Woodfuel electricity CO_2 emission factor	Constant	0.0143	t CO_2e/t wood	Estimation; NZMOE (2015)
Diesel electricity CO_2 emission factor	Constant	2.9	t CO_2e/kl	Estimation; MEMR (2016a); Assumption = diesel for transport

Table 7.31 Input variables used in the CO_2 emissions from marginal land use sub-model

Variable name	Sector of origin
Sumba DBF production	Sumba DBF Production from Marginal land Sub-model
Sumba DBF consumption	Sumba DBF Supply and Demand Sub-model
Actual year of planting start; Marginal land area available for bioenergy.	Sumba Marginal Land Development Sub-model
Trees per ha; Crop rotation cycle; Sumba woodfuel for harvest.	Sumba Feedstock Production Sub-model
National to Sumba marginal land area multiplier.	Liquid Biofuel Transition Sub-model

7.7 Conclusions

Developing the ABMIC model was a fundamental step in applying the systems dynamics approach for the assessment of increasing liquid fuel self-sufficiency in Indonesia through utilization of marginal land and appropriate technology for biofuel production. Unlike existing studies that commonly consider socioeconomic and environmental dimensions when assessing sustainable biofuel development, this study also includes the political dimension.

Through the causal loop modelling, this study formulated the dynamic problem, explained the main variables and feedback loops, identified the system archetype and the key leverage points, and designed a policy intervention.

The dynamic problem is that liquid petroleum fuel production in Indonesia has become insufficient for fulfilling the growing demand. The main purpose of the ABMIC model is to provide policy insights for increasing liquid fuel self-sufficiency through utilization of marginal land and appropriate technology for biofuel production, by learning from the behaviours generated from the complex systems.

From the causal loop modelling, it was identified that the key leverage point in increasing liquid fuel self-sufficiency in Indonesia, passed through by four feedback loops in the causal loop model, is a sense of urgency needed by the President. This is driven responsively to balance of trade and by an anticipative driver of his future vision that can strengthen and sustain the urgency level.

The causal loop model has a system archetype called “shifting the burden”. Based on analysis of the archetype, it is shown that support for DBF production for increasing liquid biofuel implementation needs to be dominated by the sense of urgency.

The boundaries of ABMIC model were set based on the model purpose, which are classified into endogenous, exogenous, and excluded types. Unlike existing studies that apply system dynamics methodology, this study treats time delay and policy as endogenous variables.

Based on interrelationships in the system for increasing liquid fuel self-sufficiency in Indonesia through utilization of marginal land and appropriate technology for biofuel production, the ABMIC model was divided into 10 sub-models: policy; DBF technology readiness; Sumba marginal land preparedness; Sumba feedstock production; DBF production from marginal land; Sumba DBF supply and demand; liquid biofuel transition; national liquid biofuel supply and demand; economic, and CO_2 emissions. The stock and flow structures were built using Stella® Architect software.

The study developed two important novel structures in system dynamics modelling, each presented in the policy sub-model and liquid biofuel transition sub-model respectively. The former modelled the interrelationships between the sense of urgency and liquid biofuel implementation performance, while the latter modelled the transition from palm biodiesel to palm drop-in biofuel in Indonesia.

The results of simulations from employing the ABMIC model are presented and discussed in Chapter 8.

CHAPTER 8
MODELLING RESULTS AND ANALYSIS

8.1 Introduction

This chapter presents and discusses the modelling results and provides policy design and analysis in the strategy for increasing liquid fuel self-sufficiency in Indonesia through the utilization of marginal land and appropriate technology for biofuel production.

Section 8.2 describes the Reference Mode and the main indicators assessed. Then, the model validation is explained in Section 8.3. Section 8.4 provides policy scenarios analysis that includes the scenario design and the policy implications.

8.2 Reference Mode

This model, *Assessment Tool of Biofuel Strategy through Utilization of Marginal Land and Innovation in Conversion Technology* (ABMIC), was developed to provide policy insights into liquid biofuel implementation in Indonesia using system dynamics methodology.

The Reference Mode defines the problem in the current system, where the liquid fuel self-sufficiency in Indonesia is low due to oil reserve depletion and procrastination in liquid biofuel implementation. It was identified that the key leverage point in addressing the issue is the sense of urgency by the President (SU) which was influenced by two types of driver. The first is the pressure from on-going difficulties, and the second is the vision from future desired condition (Chapter 2). In the Reference Mode which describes the existing condition, the future vision is ignored.

The variable parameters in the assessment comprise the future vision which is a combination of weight to vision (WVS), future vision power (FVS), and crop rotation cycle (CRC) (Table 8.1). When the future vision is not activated, the values of WVS and FVS in the Reference Mode are zero. This means SU is driven by 0% of 0 vision and 100-0% of 1 pressure, or 0% vision and 100% pressure (Chapter 7). In other words, SU is fully pressure-driven.

The CRC was set at 15 years taking account of productivity of pongamia oilseed plants which last for up to 40 years with oil yields peaking around eight years of growth

(Chapter 4), as well as to have the trees harvested for woodfuel around the peak oil years before replanting.

Table 8.1 Reference Mode policy parameters of ABMIC model

Parameters	**Units**	**Values**
Weight to vision (WVS)	dimensionless	0
Future vision power (FVS)	dimensionless	0
Crop rotation cycle (CRC)	years	15

For the assessment, the simulation applied time horizon was from 2018 till 2045 with twelve variables of main indicators set as explained in Chapter 7 and listed below:

(i) sense of urgency by the President (SU);

(ii) DBF technology technical readiness (TR);

(iii) Sumba marginal land developed area (MD);

(iv) Sumba oilseed feedstock (OSF);

(v) Sumba DBF production (r_{DP});

(vi) Sumba liquid fuel self-sufficiency (SLF);

(vii) national liquid fuel self-sufficiency (NLF);

(viii) liquid biofuel actual share (BSA);

(ix) foreign exchange saving (FES);

(x) increase in Sumba gross regional domestic product (GRDP) from DBF, oilseeds, and woodfuel (SGI);

(xi) Sumba CO_2 emissions (r_{CE}); and

(xii) national CO_2 emissions (NCE).

In terms of liquid biofuel sustainability, of the four indicators, the first indicator in the list is a political dimension, the last two are environmental, and the remaining one deals with socioeconomic aspects. The simulation outputs of those parameters are presented in Table 8.2 and Figs. 8.1 - 8.5.

The sense of urgency by the President (SU) is a political dimension in bioenergy sustainability, which has not been found in other existing bioenergy studies that use a systems dynamics approach. The SU role was described through historical facts (Chapter 2) and the structure in the model was determined considering opinion from local experts (Section 8.3.1).

The initial value for SU was estimated to be the maximum, according to the situation in 2018 (Chapter 2). Based on the simulation results, given the variables which influence the balance of trade and the fuel price difference, SU is projected to drop in the near future from 1.00 in 2018 to 0.75 but then quickly return to 1.00 in 2024 and remain around that level until 2027. Then it plummets to 0.01 in 2029 just before sharply fluctuating to a peak at 0.42 and reaching 0.32 in 2045. (Fig. 8.1, Table 8.2).

Table 8.2 Simulation output for Reference Mode of ABMIC model

Year	Sense of urgency by the President (dimensionless)	Technology Technical Readiness (dimensionless)	Sumba developed marginal land area (ha)	Sumba oilseeds feedstock (t/yr)	Sumba DBF production (kl/yr)	Sumba liquid fuel self-sufficiency (dimensionless)	National liquid fuel self-sufficiency (dimensionless)	National lliquid biofuel actual share (dimensionless)	Foreign exchange saving (billion USD/yr)	Sumba GRDP increase from DBF, oilseeds, and woodfuel (million USD/yr)	Sumba CO_2 emissions (Mt CO_2e/yr)	National CO_2 emissions (Mt CO_2e/yr)
2018	1.00	0.50	0	0	0	0.00	0.69	0.00	0.00	0.00	0.00	0.00
2019	0.89	0.81	0	0	0	0.00	0.68	0.06	2.00	0.00	0.00	0.00
2020	0.97	0.93	0	0	0	0.00	0.64	0.07	2.61	0.00	0.00	0.00
2021	0.99	0.98	0	0	0	0.00	0.67	0.08	3.09	0.00	0.00	0.00
2022	1.00	0.99	0	0	0	0.00	0.65	0.09	3.96	0.00	0.00	0.00
2023	1.00	1.00	35,783	0	0	0.00	0.70	0.11	5.22	0.00	0.00	0.00
2024	1.00	1.00	77,556	0	0	0.00	0.72	0.12	6.38	0.00	-0.28	-14.15
2025	1.00	1.00	110,850	0	0	0.00	0.73	0.13	7.36	0.00	-0.57	-28.30
2026	1.00	1.00	136,008	46,667	0	0.00	0.83	0.13	8.12	0.70	-0.85	-42.44
2027	0.56	1.00	154,132	93,333	0	0.00	1.00	0.18	15.64	1.40	-1.13	-56.59
2028	0.18	1.00	162,258	154,000	0	0.00	1.00	0.18	15.90	2.31	-1.41	-70.74
2029	0.06	1.00	163,227	219,333	0	0.00	1.00	0.06	8.51	3.29	-1.70	-84.89
2030	0.16	1.00	163,227	336,000	70,159	0.43	1.00	0.16	15.25	65.66	-2.02	-100.85
2031	0.19	1.00	163,227	452,667	109,549	0.63	1.00	0.19	20.11	100.57	-2.40	-119.92
2032	0.25	1.00	163,227	569,333	159,048	0.88	1.00	0.25	28.35	143.32	-2.78	-138.93
2033	0.08	1.00	163,227	686,000	215,746	1.00	1.00	0.08	7.60	192.96	-3.25	-162.75
2034	0.13	1.00	165,620	802,667	266,759	1.00	1.00	0.13	15.79	238.10	-3.54	-176.95
2035	0.23	1.00	167,856	919,333	303,552	1.00	1.00	0.23	31.60	271.97	-3.83	-191.58
2036	0.32	1.00	169,948	1,036,000	329,361	1.00	0.96	0.32	48.02	294.90	-4.13	-206.55
2037	0.35	1.00	171,904	1,152,667	363,268	1.00	0.95	0.34	53.89	326.74	-4.43	-221.40
2038	0.11	1.00	173,733	1,152,667	385,452	1.00	0.94	0.11	17.21	349.96	-4.94	-247.10
2039	0.14	1.00	175,443	1,152,667	385,452	1.00	0.91	0.14	23.59	353.08	-4.98	-248.80
2040	0.15	1.00	177,043	1,152,667	385,452	1.00	0.89	0.15	26.82	353.55	-5.01	-250.59
2041	0.15	1.00	178,539	1,152,667	385,452	1.00	0.86	0.15	28.57	353.99	-5.05	-252.47
2042	0.15	1.00	179,938	1,152,667	385,452	1.00	0.83	0.15	29.94	354.40	-5.09	-254.43
2043	0.15	1.00	181,246	1,152,667	385,452	1.00	0.83	0.15	31.19	354.79	-5.13	-256.50
2044	0.40	1.00	182,469	1,152,667	385,452	1.00	0.80	0.29	62.23	360.57	-5.17	-258.67
2045	0.32	1.00	183,614	1,152,667	385,452	1.00	0.80	0.28	62.69	360.94	-5.22	-260.95

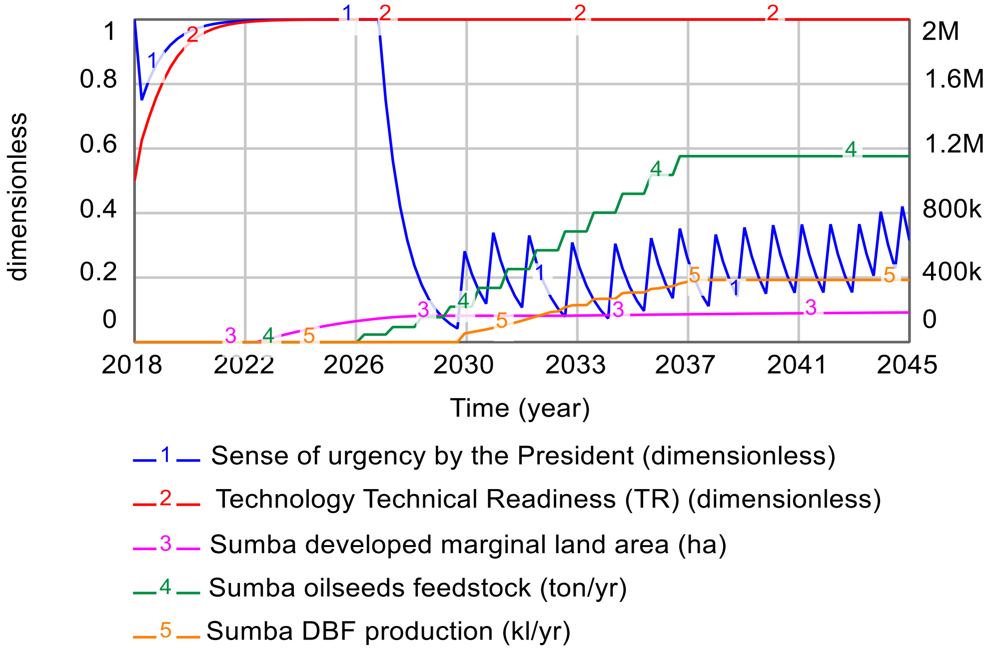


Fig. 8.1 Dynamics of indicators for DBF production for Reference Mode of ABMIC model

Despite the overall pattern, the high SU in 2018 - 2027 can sufficiently drive up completion of DBF technology technical readiness and the start time of developing the marginal area on Sumba in 2023. Thus, oilseeds feedstock production can start in 2026 and enable the first DBF production to commence in 2030 (Fig. 8.1, Table 8.2).

Thus, DBF production is projected to start supporting the liquid fuel self-sufficiency for Sumba in 2030 and achieve 1.00 (fully sufficient) in 2032 – 2045. At the national level, liquid biofuel self-sufficiency is projected to increase from 0.67 in 2018 to 1 in 2027 and stay at this maximum up to 2034 before gradually decreasing to around 0.80 in 2045 (Fig. 8.2, Table 8.2).

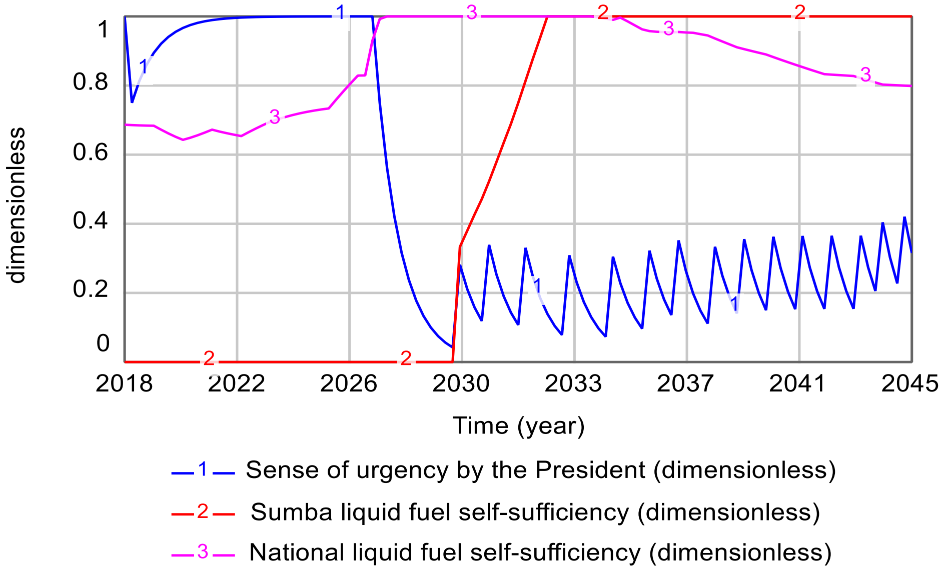


Fig. 8.2 Dynamics of indicators for liquid fuel self-sufficiency for Reference Mode of ABMIC model

The fluctuation in SU causes changes in the liquid biofuel target which in turn stimulates fluctuation in national the actual share of liquid biofuel in 2028 - 2045 (Fig. 8.3, Table 8.2). The SU drives up the liquid biofuel share target and the national liquid biofuel actual share to reach 0.32 and 0.28 respectively in 2045.

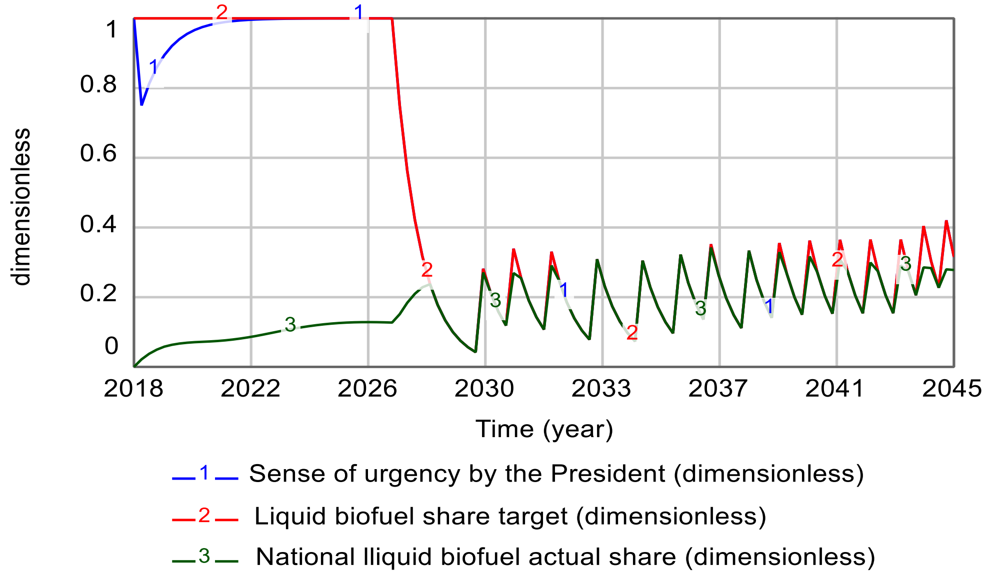


Fig. 8.3 Dynamics of indicators for liquid biofuel share for Reference Mode of ABMIC model

Even though the national liquid biofuel actual share fluctuates, the potential economic impacts from the strategy implementation by 2045 are still promising. It is projected that by 2045 the potential of foreign exchange saving reaches USD 62.7 billion/year and the Sumba GRDP increase as a result of DBF, oilseeds, and woodfuel achieves USD 361 million/year (Fig. 8.4, Table 8.2).

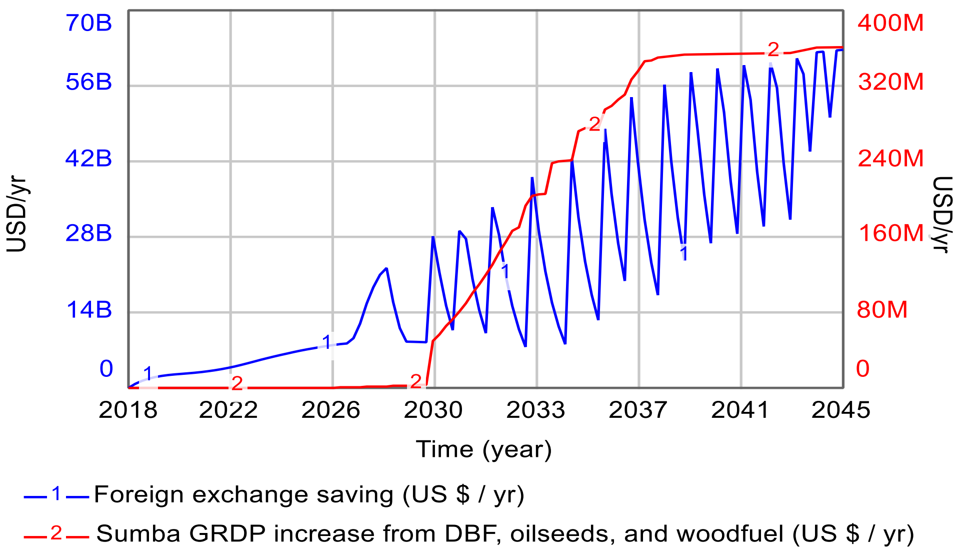


Fig. 8.4 Dynamics of indicators for selected socioeconomic impacts for Reference Mode of ABMIC model

The potential impact of liquid biofuel implementation to CO_2 emissions reduction is substantial. It is projected that by 2045, potential CO_2 emissions reduction reaches 5.0 Mt CO_2e/year for Sumba and 261 Mt CO_2e/year at the national level (Fig. 8.5, Table 8.2). By 2030, the contribution to reduced emissions at the national level is projected to exceed 100 Mt CO_2e/year or around 12% of the Indonesian international commitment for climate change mitigation through the Nationally Determined Contribution (NDC) of Indonesia as outlined for the Paris Climate Agreement (Chapter 2).

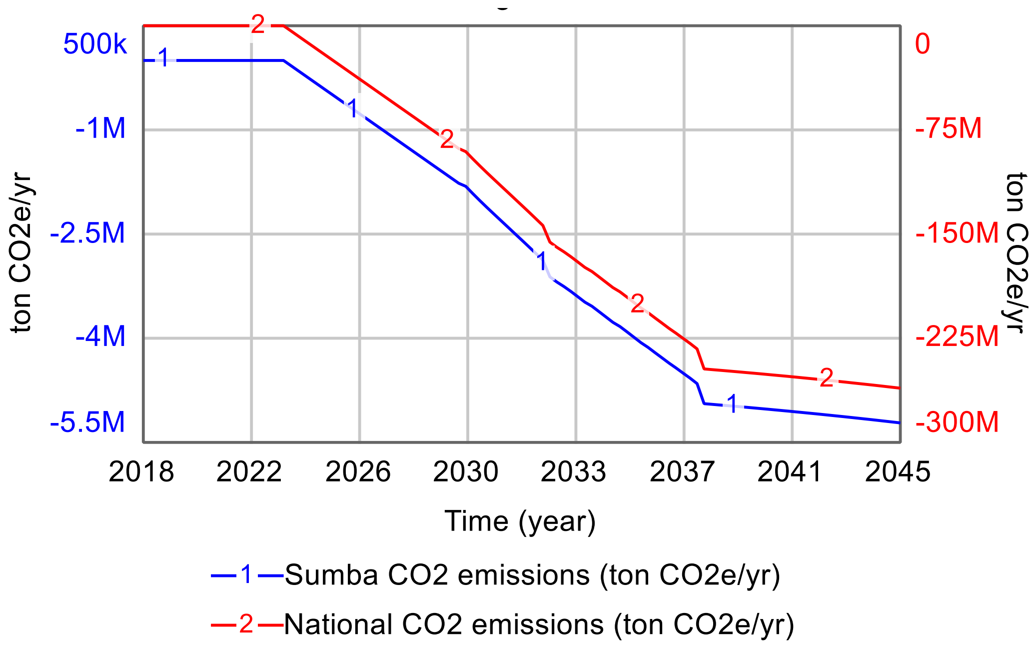


Fig. 8.5 Dynamics of indicators for CO_2 emissions for Reference Mode of ABMIC model

8.3 Model validation

Model validation is important for building confidence in the structure and behaviour of a model before the policy design and evaluation can be accomplished (Sterman, 2000). The validation aims to ensure that the model is sufficiently robust and represents the real system, based on the model's purpose.

This research did not undertake point-prediction but aimed to learn the system's behaviour due to policy intervention. Therefore, the validations do not need to be so detailed as when analysing statistical parameters.

Validation of the constructed model was carried out using several criteria that are categorized into structural validation and behavioural validation (Barlas (1989); Senge (1990); Sterman (2000)). The criteria of structural tests comprise parametric appropriateness, dimensional consistency, mass balance, and face validation, whereas the behavioural tests comprise tests of extreme condition and sensitivity. The model usefulness was also tested by involving several representatives from the federal government institutions.

The process for elicitation of expert knowledge considered several factors such as the modelling purpose; the task being performed; the number of people being involved; the time available, and the cost (Luna-Reyes & Andersen, 2003). In this study the elicitation was applied in (i) getting the big picture of policy; (ii) designing the equation for "increasing urgency" flow in policy sub-model, and (iii) determining factors which are qualitative variables that need to be quantified ("soft" variables), such as in policy sub-model, DBF technology readiness sub-model, and Sumba DBF production sub-model.

8.3.1 Structural validation

The structural validation determined to what extent the structure of the model matches the structure of reality (Barlas, 1989). The model consistency was checked with the knowledge of real systems relevant to the purpose, including mathematical equations and basic physical conservation laws. For example, the land stock could not be a negative value. In the developed model the structural tests comprised of the parametric appropriateness, dimensional consistency, mass balance, and face validation.

8.3.1.1 Parametric appropriateness

The parameter assessment aimed to ensure that every parameter has meaning equivalence with the real system (Sterman, 2000). This test was carried out during building the whole model through literature assessment, direct professional experience, interviews (Appendix C, F), focus groups (Appendix D, E), and personal communications (Appendix H).

8.3.1.2 Dimensional consistency

Dimensional consistency in the ABMIC model was automatically checked in the Stella® Architect software during using the software for calculations.

8.3.1.3 Mass balance

This test was conducted to ensure that the equations had mass inputs equal to mass outputs. The software for systems dynamics modelling automatically applies mass conservation in enabling calculations of stocks and flows. However, the mass balance for converters which are not directly influenced by stocks and flows, need to be checked as was conducted in this study including for the sub-models of oilseeds feedstock production, DBF production, liquid biofuel supply and demand, and liquid biofuel transition.

8.3.1.4 Face validation

Face validity test is a subjective validation when looking at the model for the first time and deciding whether the variables, their causal relationships and behaviour make sense to the expert participant (Black, 2002).

This study designed a novel policy structure for assessing the dynamics of the sense of urgency by the President (SU). In testing the structure, a face validity test was conducted through interviews with three experts who all hold a PhD degree based on research in Indonesian policies that applied a systems dynamics approach (Appendix F). Before conducting the interview, each of the participants were sent an interview guideline (Appendix A).

The test emphasized whether the variables and the causality in the policy structure were logical or not. All three experts agreed that the policy structure made sense as an integrated part of the whole assessment tool and suggested some improvements. For example, it was suggested to decompose the components of balance of trade in more detail and treat each as endogenous variable where possible (Arsegianto, 2017).

After the SU structure was improved based on the experts' inputs and the recently significant updates in the real system, an informal discussion was conducted for increasing confidence in the equation for "increasing SU" flow. Two options of parameter values for Reference Mode were discussed to determine one which is the most representing the real system (Tasrif, 2018).

8.3.2 Behavioural validation

The behavioural test aims to assess the consistency of the model-generated behaviours in matching with those observed/expected/anticipated from the real system (Barlas, 1996). The model behavioural validity was tested through extreme condition and sensitivity tests by varying future visions as a combination of weight to vision (WVS) and future vision power (FVS).

8.3.2.1 Extreme condition test

This test aimed to ensure that when subjected to extreme conditions, the model behaves logically or similar to what might be anticipated from the real system (Sterman, 2000).

The extreme condition tested is the condition of *"no urgency"* where WVS is equal to 1.00 and FVS is equal to 0.00. This implies there is no vision nor pressure to drive any sense of urgency by the President (SU). The behaviour under this extreme condition was compared with the Reference Mode where both WVS and FVS are zero which means SU is fully pressure-driven due to the future vision that has not been activated.

While SU in Reference Mode is driven by 0% vision and 100% pressure, SU in the extreme condition is not driven by either vision or pressure. Thus, unlike the Reference Mode which SU fluctuates wildly due to the high pressure and no vision, SU in the extreme condition declines from the initial value of 1.00 in 2018 to zero in 2023 where it remains up to 2045, due to the absence of driver (Fig. 8.6).

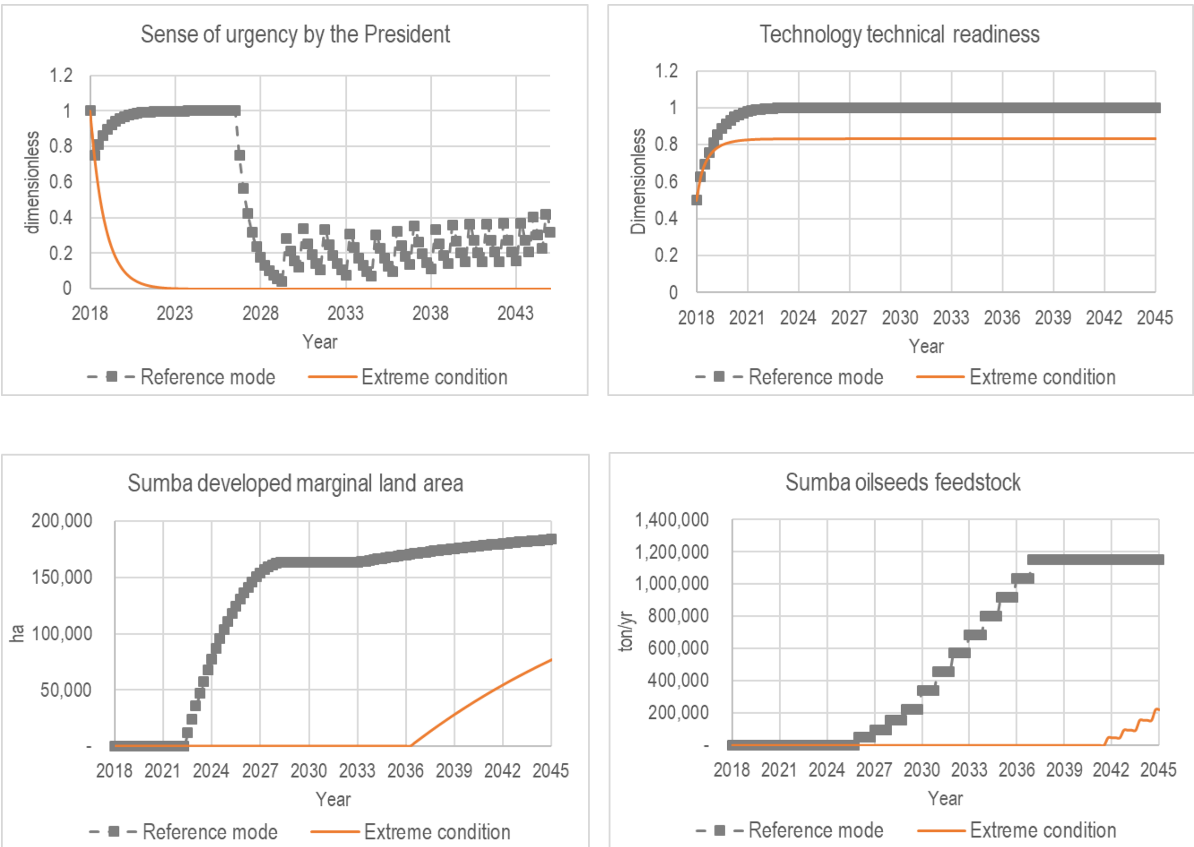


Fig. 8.6 Extreme condition test of ABMIC model for “no urgency” condition

Such low SU profile results in an insufficient driver to start DBF production by 2045 which requires full readiness of DBF technology and a certain level of oilseeds feedstock production. The low level of Sumba marginal land developed area and Sumba oilseeds feedstock as shown in Fig. 8.6 was due to the DBF technology technical readiness which is one of the key factors needed to support marginal land development in time (Chapter 7).

As there is no DBF production in Sumba, liquid fuel self-sufficiency has no support, and thus national liquid fuel self-sufficiency is built only by production of oil fuel and palm biodiesel, the existing liquid biofuel.

In 2018-2033 national liquid biofuel actual share (BSA) comes from palm biodiesel which has a price ratio of biofuel to oil fuel (PRF) of less than one. Then, in 2033-2045 BSA becomes zero due to (i) no DBF production, and (ii) PRF is more than one. Hence SU becomes zero and thus the liquid biofuel share target does not exist (Fig. 8.7).

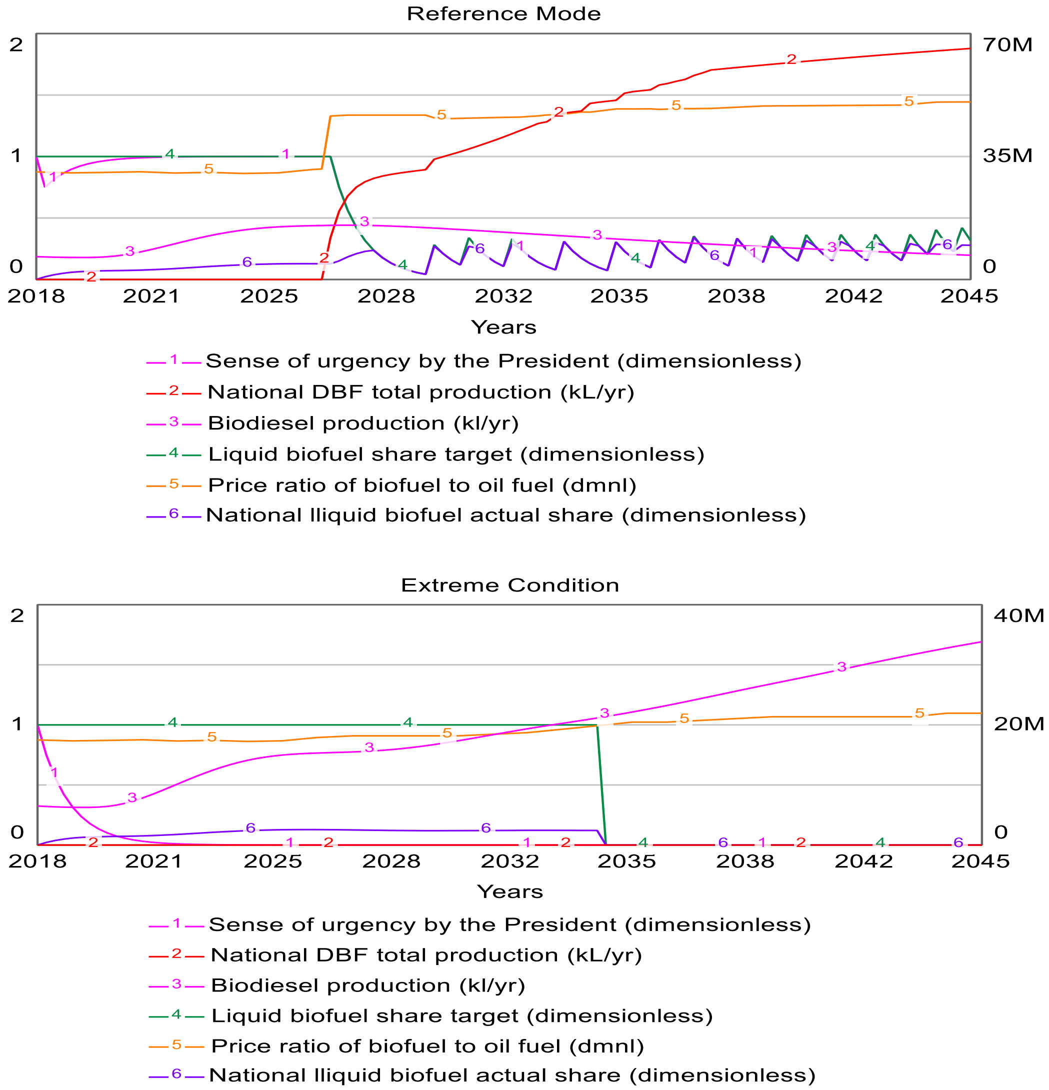


Fig. 8.7 Assessment of national liquid biofuel actual share under the extreme condition test of no sense urgency by the President (SU) using ABMIC model

Thus, the profile of Sumba oilseeds feedstock and Sumba DBF production in extreme conditions results in much lower values of foreign exchange saving, GRDP increase, and CO_2 emissions reduction, based on associated variables.

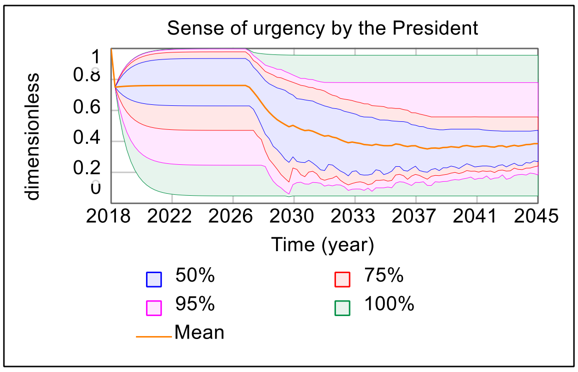
The model behaviour under this extreme condition was as anticipated in the real system, and thus, it improved the ABMIC model validity.

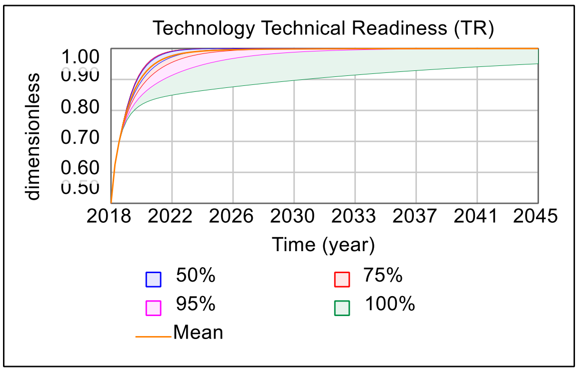
8.3.2.2 Sensitivity test

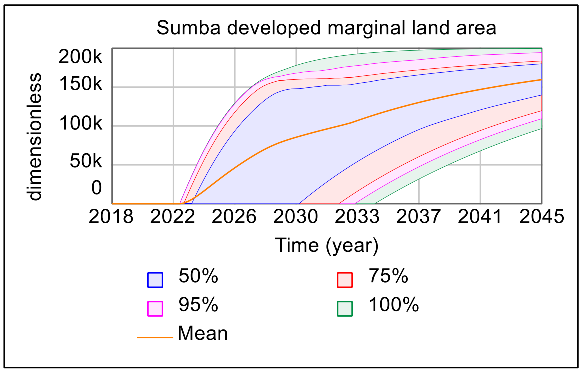
Sensitivity analysis is necessary to ensure that uncertainties in assumptions do not significantly change the model behaviour (Sterman, 2000). A sensitivity test was conducted to evaluate how changes in behaviours respond to a change in a policy parameter. A parameter to which the model is highly sensitive can be identified as the key leverage point which has a significant effect on the system behaviour (Barlas, 1996).

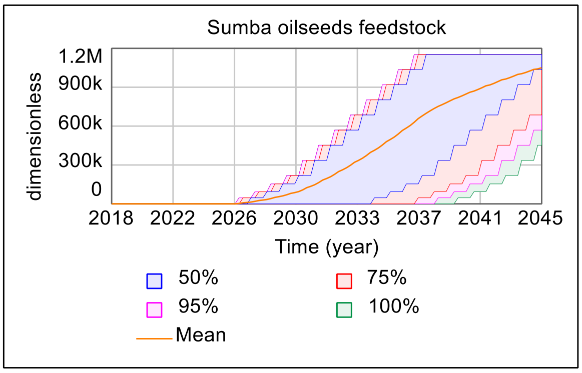
The sensitivity analysis was carried out by varying *"future vision"* which is a combination of FVS and WVS, where CRC is 15 as in Reference Mode. For the analysis, simulations were performed using Stella® Architect software, where the variation ranges of WVS and FVS were each set from 0 to 1 in uniform distributions, and the simulations run in 500 random samplings.

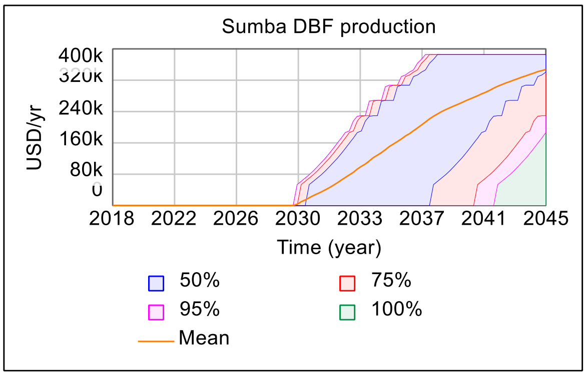
Fig. 8.8 shows the sensitivity test results which consist of the indicator values against combined values of WVS and FVS, the distribution in each confidence bound, and the mean value. The patterns and peaks against modifications in inputs for the "future vision" are similar. Moreover, the wide range of the indicator values confirmed that the sense of urgency by the President (SU) is the key leverage point in the system. Thus, the model passes the sensitivity test and its validity is increased.

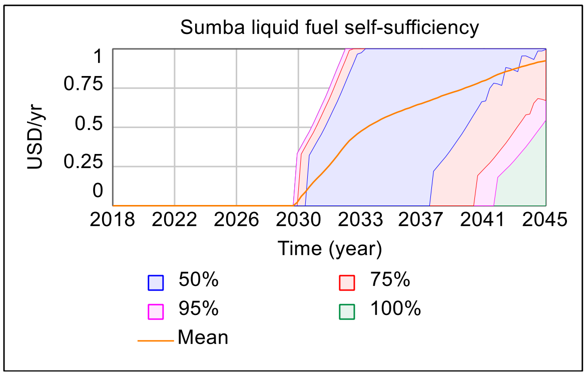

Sense of urgency by the President
dimensionless
1
0.8
0.6
0.4
0.2
0
2018 2022 2026 2030 2033 2037 2041 2045
Time (year)
50%
75%
95%
100%
Mean

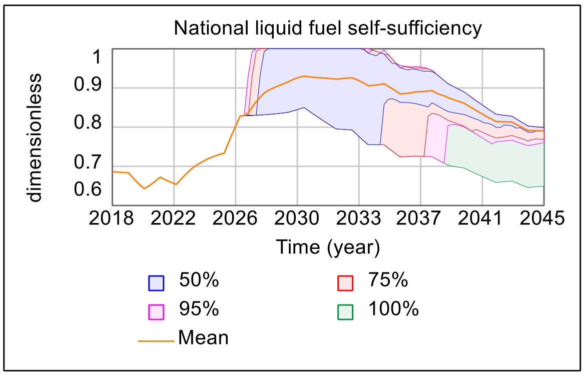

Technology Technical Readiness (TR)
dimensionless
1.00
0.90
0.80
0.70
0.60
0.50
2018 2022 2026 2030 2033 2037 2041 2045
Time (year)
50%
75%
95%
100%
Mean

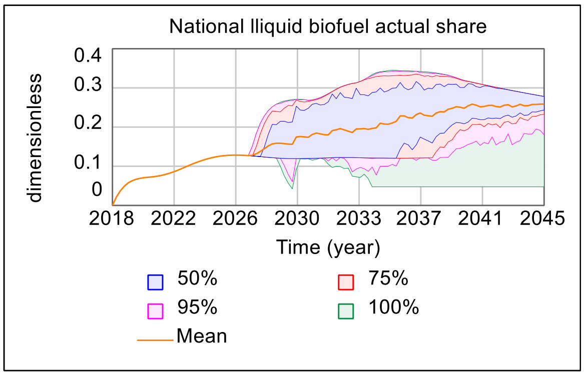

Sumba developed marginal land area
dimensionless
200k
150k
100k
50k
0
2018 2022 2026 2030 2033 2037 2041 2045
Time (year)
50%
75%
95%
100%
Mean


Sumba oilseeds feedstock
dimensionless
1.2M
900k
600k
300k
0
2018 2022 2026 2030 2033 2037 2041 2045
Time (year)
50%
75%
95%
100%
Mean


Sumba DBF production
USD/yr
400k
320k
240k
160k
80k
0
2018 2022 2026 2030 2033 2037 2041 2045
Time (year)
50%
75%
95%
100%
Mean


Sumba liquid fuel self-sufficiency
USD/yr
1
0.75
0.5
0.25
0
2018 2022 2026 2030 2033 2037 2041 2045
Time (year)
50%
75%
95%
100%
Mean


National liquid fuel self-sufficiency
dimensionless
1
0.9
0.8
0.7
0.6
2018 2022 2026 2030 2033 2037 2041 2045
Time (year)
50%
75%
95%
100%
Mean


National lliquid biofuel actual share
dimensionless
0.4
0.3
0.2
0.1
0
2018 2022 2026 2030 2033 2037 2041 2045
Time (year)
50%
75%
95%
100%
Mean

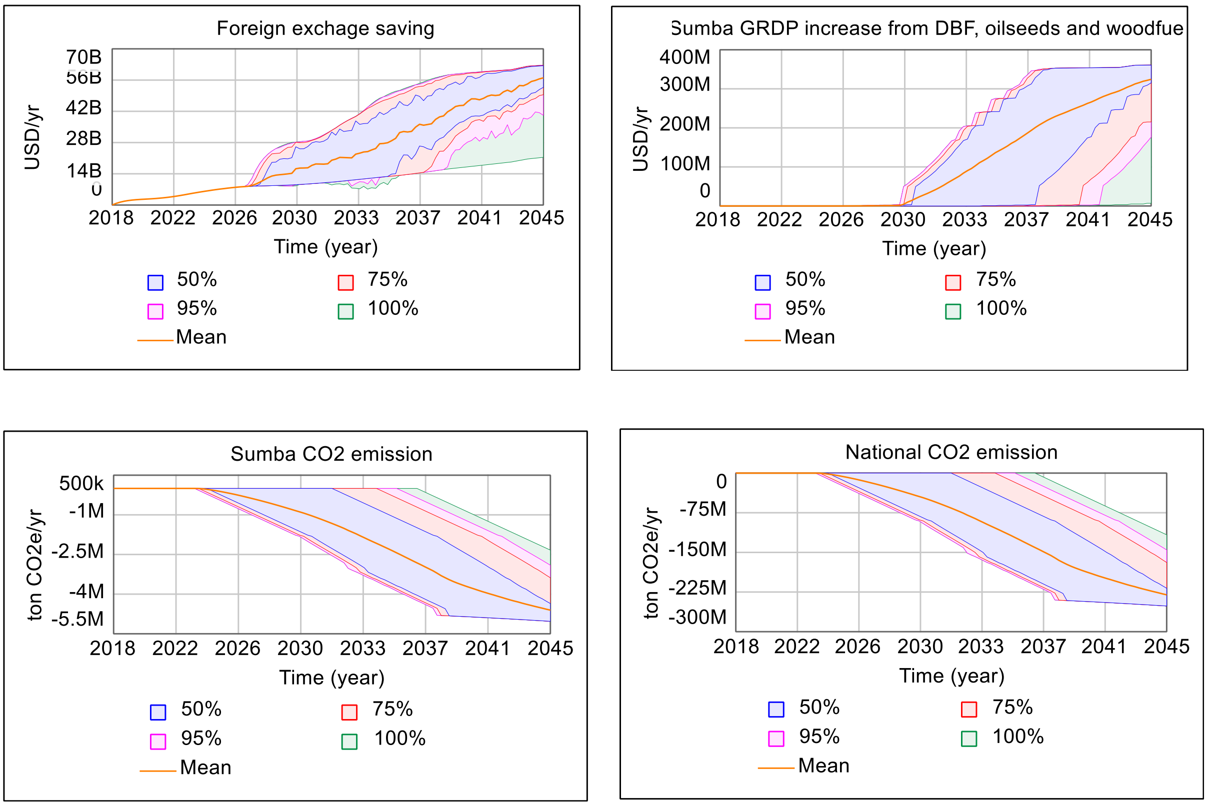


Fig. 8.8 Test of sensitivity of ABMIC model to the “future vision” parameters.

8.3.3 Model usefulness

To test the model’s usefulness, five director-level officials from four federal government institutions as potential model users were invited to give opinion during April-May 2017 (Appendix G) and the results are shown in Table 8.3. The four indicators were adopted from Musango (2012).

The institutions consisted of The Ministry of Environment and Forestry (MOEF), The Ministry of Energy and Mineral Resources (MEMR), The Ministry of Research, Technology, and Higher Education (MRTHE), and The Ministry of Industry (MOI). MOEF and MEMR are the major potential users of the model since they play the key role in policy making around the study topic whereas MRTHE and MOI are also potential users since they are significantly relevant in strategy implementation. From MEMR, besides the on-job Director, the former Director of Bioenergy who was holding another position at MEMR was invited to participate.

The participants were each given an interview guideline (Appendix A) as well as a written questionnaire (Appendix G) to test the relevance, reliability, practicability, and importance of the model and to capture some details for possible opportunities for more comprehensive use of the model in strategy implementation. Each of the interview meetings started with a presentation about the research including the modelling results.

Table 8.3 Result of model usefulness test in indicators rankings

Indicator	Government institution					Average	Rank
	MOEF	MEMR1	MEMR2	MRTHE	MOI		
Relevance	3	3	3	3	2	2.8	High
Reliability	3	3	3	2	3	2.8	High
Practicability	3	3	3	2	3	2.8	High
Importance	3	3	3	3	2	2.8	High

Scoring: Degree of usefulness 1=low; 2=medium; 3=high.

The three participants from the two key institutions of potential model users gave the highest score for all indicators, while the two additional potential model users gave mixed scores among high and medium (Table 8.3).

The respondents also provided comments and inputs on the model as well as on its value for strategy implementation. MOEF and MEMR strongly supported the proposed strategy and put high confidence on it. In improving the practicality, MOEF suggested applying a heterogeneous plantation on marginal land, while MEMR suggested performing a "what-if" analysis related to palm oil projections. In increasing the relevance and importance, MOI suggested elaborating the model to show the role and position of the private sector. In increasing the reliability and practicality, MRTHE suggested that the model could be used as a planning tool in conjunction with existing tools.

The model was revised to accommodate some of these suggestions, particularly inclusion of palm oil as the current main feedstock in liquid biofuel production in Indonesia. The other inputs provide an opportunity for increasing the model usefulness further in relevant sectors.

8.4 Policy scenarios and analysis

This study developed scenarios to assess the response of the proposed biofuel system to intervention rather than to change prediction. This section outlines and analyses scenarios which show how the model behaves when the future vision is activated to drive the sense of urgency by the President (SU).

The scenarios were designed to see the effect of SU to liquid fuel self-sufficiency through the strategy, and how a policy intervention might affect liquid fuel self-sufficiency in Indonesia. As the strategy has a simultaneous effect on CO_2 emissions reduction, the scenarios were also simulated to assess this effect.

The policy parameters to which the system responds comprise weight to vision (WVS), future vision power (FVS), and crop rotation cycle (CRC). In terms of policy modelling (Chapter 3), the future vision elements WVS and FVS determine "increasing in urgency" flow or the decision point which affects SU stock or state of condition. In addition, CRC influences the "planting and growing" decision point which in turn influences oil feedstock production.

The policy experiment was divided into two stages:

- variation of future vision to assess the implication in planting delay; and
- application of the future vision magnitude which resulted in the best system performance to the next set of scenarios. This optimized crop rotation cycle (CRC) for accommodating both oil feedstock productivity and climate change mitigation.

8.4.1 Vision scenarios (minimizing delay)

8.4.1.1 Design of vision scenarios

The sense of urgency by the President (SU) determined the starting time of DBF production from the marginal land-based feedstock, as well as the national liquid biofuel share target.

One of the most important aspects in analyzing the impact of SU on the liquid fuel self-sufficiency strategy was the delays at various stages in the DBF technology technical readiness and the marginal land area development for DBF production. These delays led to a delay in planting the crop on marginal land to supply the required DBF feedstock volume for running the first DBF plant. These delays were in turn manifested in a delay in the national liquid fuel self-sufficiency.

The future vision was added as an anticipative action to stabilize and increase SU which in the Reference Mode, fluctuated due to it being driven only by the pressures from the balance of trade and fuel price difference (Chapter 7).

To see how the system's performance is affected by the future vision through SU, three vision scenarios (Table 8.4) were set for the assessment:

- Low Vision (LV) Scenario,
- Medium Vision (MV) Scenario, and
- Full Vision (FV) Scenario.

Table 8.4 Design of vision scenarios: Full Vision (FV), Medium Vision (MV) and Low Vision (LV)

Scenario	Weight to vision (WVS)	Future vision power (FVS)	Crop rotation cycle (CRC)	Pressure contribution to SU (1-WVS)	Vision contribution to SU (WVS*FVS)	Total SU
Reference Mode / Full Pressure (FP)	0	0	15 yrs	100%	0%	100%
Full Vision (FV)	1	1	15 yrs	0%	100%	100%
Medium Vision (MV)	0.5	0.7	15 yrs	50%	35%	85%
Low Vision (LV)	0.5	0.1	15 yrs	50%	5%	55%

8.4.1.2 Implications for the main indicators across vision scenarios

Table 8.4 and Fig. 8.9 show that an increase in the sense of urgency by the President (SU) is generated by the sum of pressure and vision, leading to an earlier starting time of DBF production as well as higher performance. At a fixed WVS such as in the LV Scenario and MV Scenario, an increase in future vision increased and stabilized the system's performance.

The maximum and most stable SU was achieved in the FV Scenario which is driven by 100% vision and 0% pressure, or fully vision-driven. This was followed by the MV Scenario which is driven by 35% vision and 50% pressure, and then the LV Scenario driven by 5% vision and 50% pressure. For the Reference Mode which is fully pressure-driven, the SU profile in 2018-2027 is high and seemingly identical with the FV Scenario. However, in 2029 it suddenly falls to slightly above zero, and then fluctuates at low levels up to 2045, whereas the FV Scenario stays up at the high profile. (Fig. 8.9).

An increase in SU leads to a faster time to get the DBF technology technical readiness (TR) completed. Under the Reference Mode, which SU is driven by 100% pressure and at FV Scenario which SU is driven by 100% future vision, TR is projected to be completed by 2023. For the MV Scenario, SU is also sufficient to drive TR being completed in 2023, whereas for the LV Scenario, it is three years slower.

An increase in SU also speeds up the Sumba marginal land developed area (MD). For the Reference Mode and FV Scenario, SU drives up marginal land development to begin in 2023, while for the LV Scenario and MV Scenario, it gets slower by two years and nine years respectively. In the FV Scenario, it is projected that by 2045 all available Sumba marginal land area will have been developed for energy cropping. While for the baseline Reference Mode, MV Scenario and LV Scenario, by 2045 the available Sumba marginal land area has not been completely developed, with 184,000 ha, 174,000 ha and 129,000 ha (or 92%, 77% and 65% of total available area) respectively is developed.

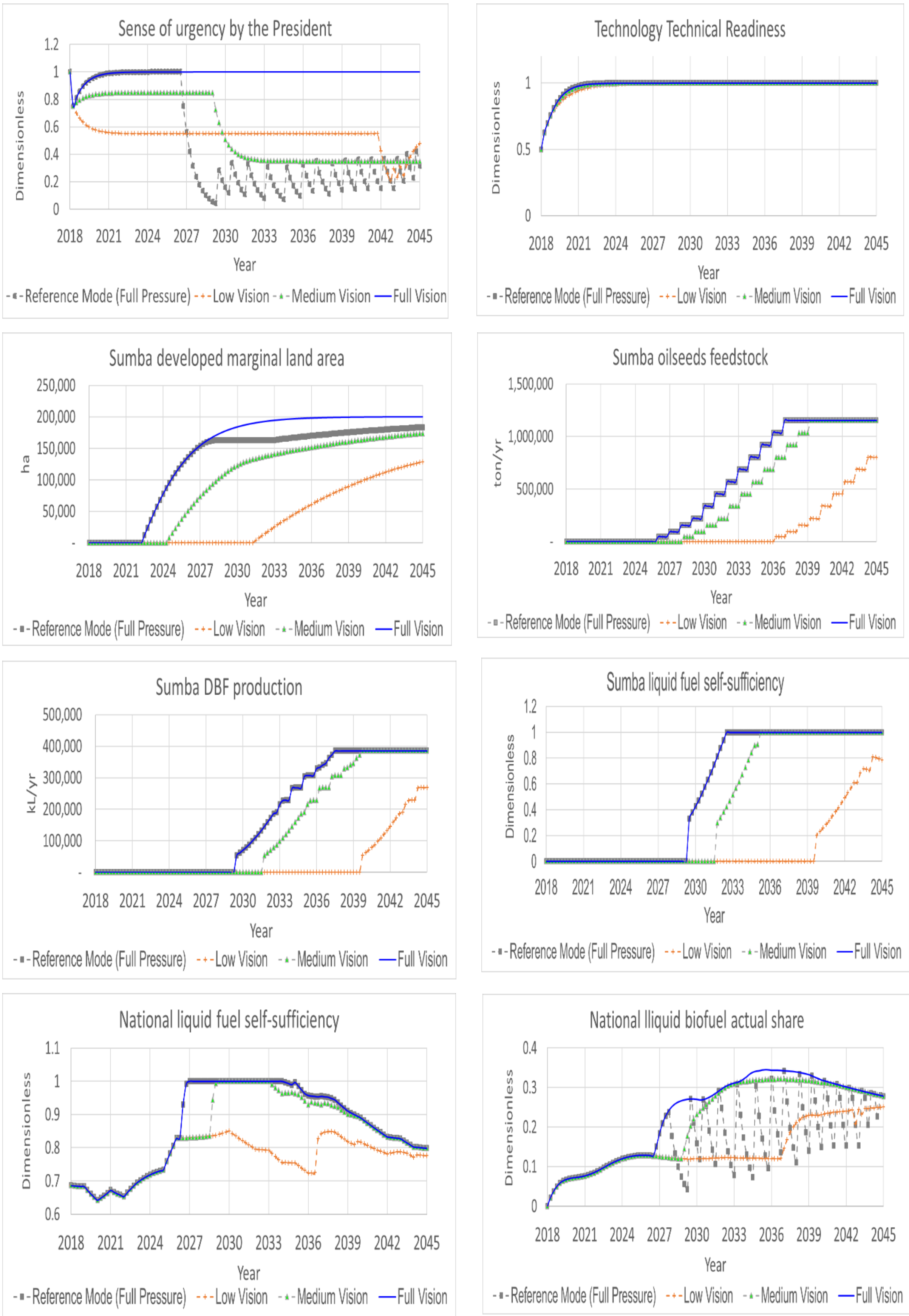


Fig. 8.9 Liquid biofuel implementation across the low (LV), medium (MV), and full (FV) vision scenarios

The increase in the marginal land developed area increases production of Sumba oilseeds feedstock (OSF). Based on the progress in DBF technology readiness and marginal land development, it was projected that at SU with full pressure and full vision, OSF from marginal land starts in 2026 and peaks in 2037 at 1.2 Mt/yr. For the MV Scenario, the same pattern and values are achieved but two years slower and for the LV Scenario, the oilseeds feedstock production has not even peaked by 2045.

Based on OSF patterns, it was projected that for the Reference Mode and FP Scenario, the first DBF plant will start up in 2030 and the peak DBF production (r_{DP}) will reach around 385,000 kl/yr in 2038. Meanwhile, the MV Scenario results in a similar pattern and values but two years later. For the LV Scenario, the r_{DP} is projected to start ten years later and by 2045 has not yet peaked.

Sumba liquid fuel self-sufficiency (SLF) exists after DBF production starts. For the Reference Mode and FV Scenario, it was projected that SLF increases from 0.33 in 2030 to 1 in 2033 and stays at that level up to 2042. For the MV Scenario, it starts and peaks three years slower with the starting point at 0.30, while at SU with low vision, it starts seven years later at 0.20 and has not peaked by 2045.

National liquid fuel self-sufficiency (NLF) is determined by liquid fuel demand, oil fuel production, biodiesel production, and total DBF production. At SU of all scenarios, NLF is projected to increase from 0.69 in 2018 to 0.83 in 2026. Then it increases: for the FP Scenario and FV Scenario, to 1 in 2027 where it remains up to 2034; for the MV Scenario to 1 in 2029 and remaining till 2033, while for the LV Scenario it reaches 0.84 in 2030 and then decreases to 0.73 in 2037 before quickly going up to 0.85 in 2038. Then, in all scenarios it goes to 0.80 in 2045.

The FV Scenario results in the same NLF pattern as the Reference Mode which is pressure driven, meaning that both scenarios generate equal SU for progressing until DBF production starts (Fig. 8.9). This is because given the assumptions, the values of pressure from the balance of trade and fuel price difference in the Reference Mode, generates a high SU as in the FV Scenario. Note that NLF is influenced by the oil fuel demand, oil fuel production, and liquid biofuel supply before oil feedstock from marginal land is ready, and DBF production has started outside of Sumba island using palm oil feedstock (Fig. 8.10).

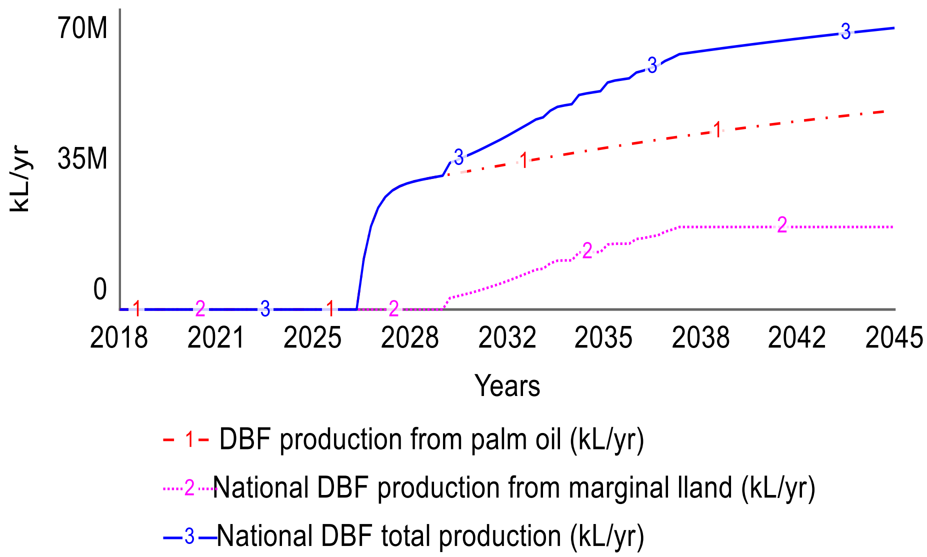


Fig. 8.10 Dynamics of national DBF production for the FV Scenario

The actual share of national liquid biofuel (BSA) is determined by national liquid fuel demand, liquid biofuel share target, and liquid biofuel consumption. Unlike the Reference Mode behaviour which fluctuates, the results of all vision scenarios show no such phenomenon. At all scenarios, NLF is projected to increase from 0 in 2018 to 0.12 in 2027; for the FV Scenario, it then increases to 0.35 in 2036 and decreases to 0.25 in 2045; for the MV Scenario and LV Scenario, it starts two years and ten years later respectively and performs lower values (Fig. 8.11).

It is shown that in the Reference Mode, unlike the national liquid biofuel actual share (BSA) which is fluctuating, the national liquid fuel self-sufficiency (NLF) has the same value and consistency as in the FV Scenario. This is due to (i) SU at early years before DBF production is maximum (Fig. 8.11); (ii) the dynamics of DBF production at the national level is merely a multiplication of the Sumba performance by a constant factor (rather than based on more specific observations on different islands), and (iii) the effect of liquid biofuel demand on supply was excluded (as discussed in Chapter 9).

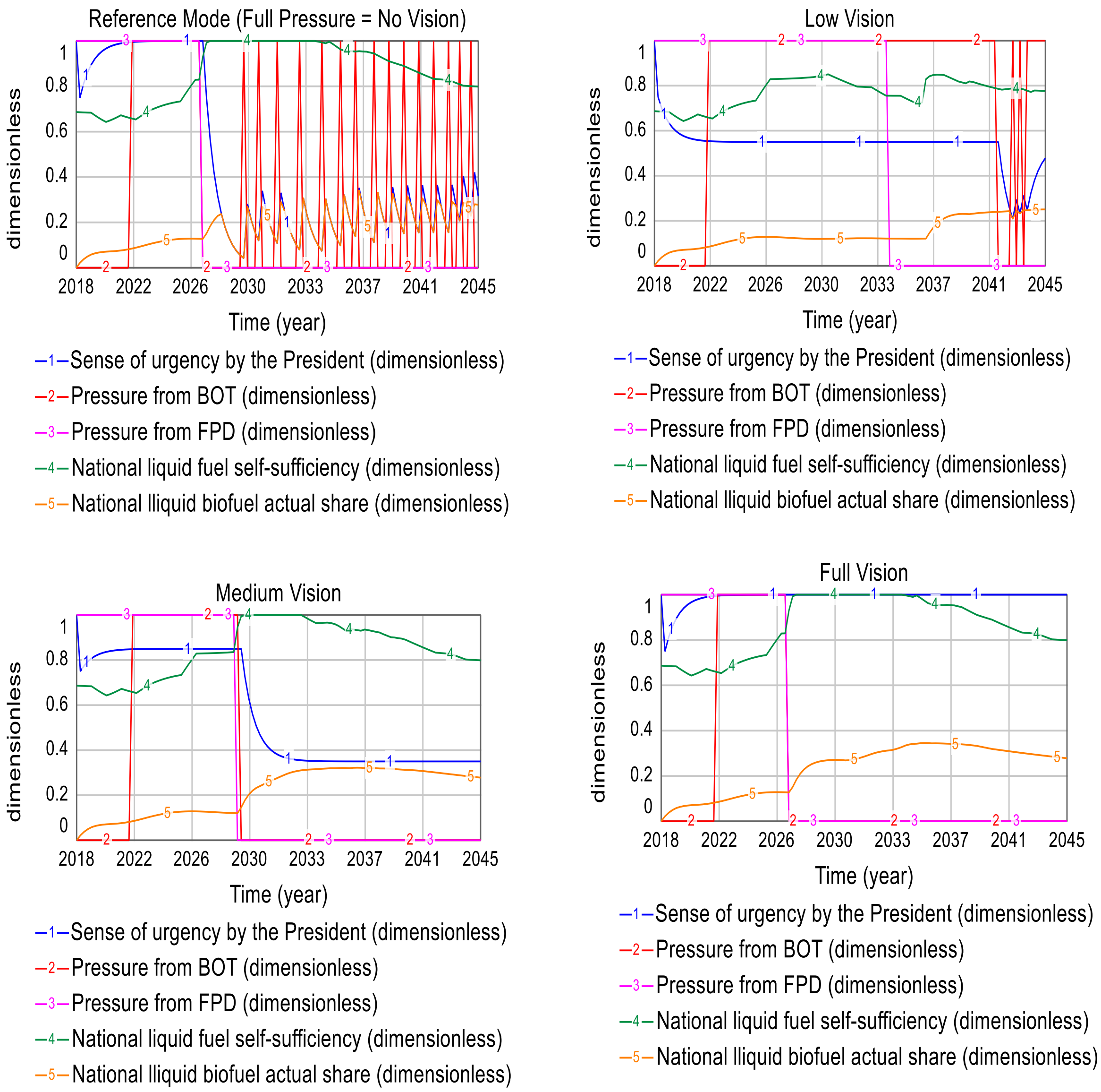


Fig. 8.11 Simulations output of oilseed crop planting delay across scenarios

The results show that NLF for all the scenarios in 2045 never reached 1 (Fig. 8.11). This is caused by the limitation of the marginal land area for DBF feedstock production. Fig. 8.12 illustrates how marginal land available area affects national liquid fuel self-sufficiency (NLF) as well as national liquid biofuel actual share (BSA). The marginal land available area in the Reference Mode is 200,000 ha on Sumba or was estimated to be 10 M ha at the national level (Chapter 7). Given the assumptions, the use of a larger land area, such as 38.5 million ha with the same productivity profile, can result in national liquid fuel self-sufficiency of 1 by 2045, whereas the national liquid biofuel actual share reaches 0.46.

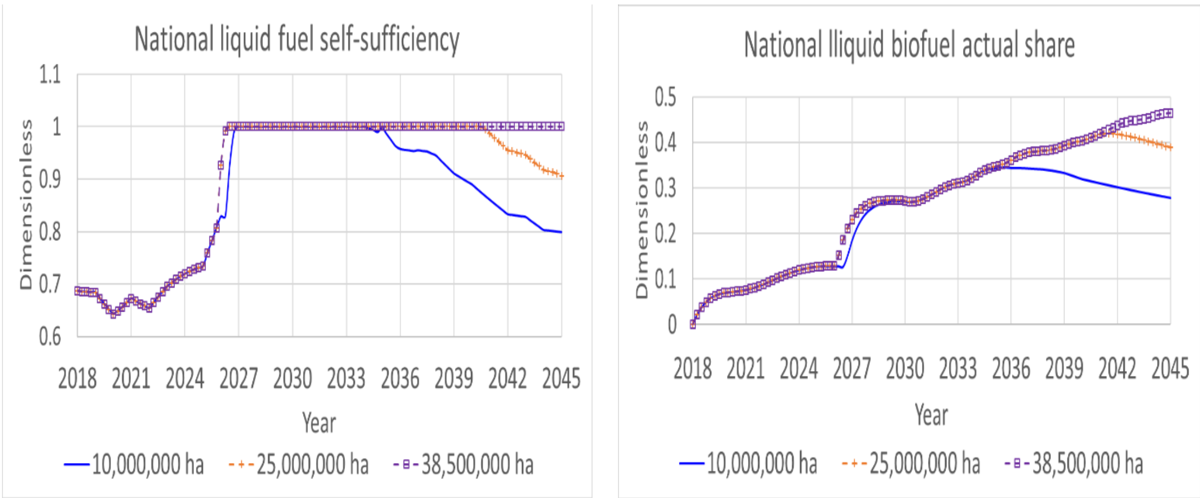


Fig. 8.12 Effect of marginal land available area to liquid biofuel (WVS 1, FVS 1, CRC 15)

Two economic indicators were selected for assessing the effect of future vision: national foreign exchange saving (FES) and Sumba GRDP increase from DBF, oilseeds, and woodfuel (SGI).

An increase in SU leads to an increase in national foreign exchange saving (FES). For the FV Scenario, it is projected that FES significantly increases from USD 9.2 billion/year in 2027 to USD 62.7 billion/year in 2045. For the MV and LV Scenarios, the significant increase starts two years and ten years later respectively and performs less over time (Fig. 8.13).

The Reference Mode (FP) and Full Vision (FV) Scenario have the same starting and final values but sharply fluctuate as in the national liquid biofuel actual share pattern. Consequently, the accumulated FES through the Reference Mode would be much lower than SU with full vision.

The investment in DBF technology innovation is an anticipated present cost that would have a short-run negative effect on economic growth. It was assumed the DBF technology innovation investment of USD 100 M was disbursed in the five-year period from 2018 to 2023 (Chapter 7). For the FV Scenario, the impact in FES in line with the reduction in oil fuel imports, resulted in long-run revenues at a much greater value. For example, in 2045 it achieves USD 62.7 billion/year, being thousands of times the investment in DBF technology innovation.

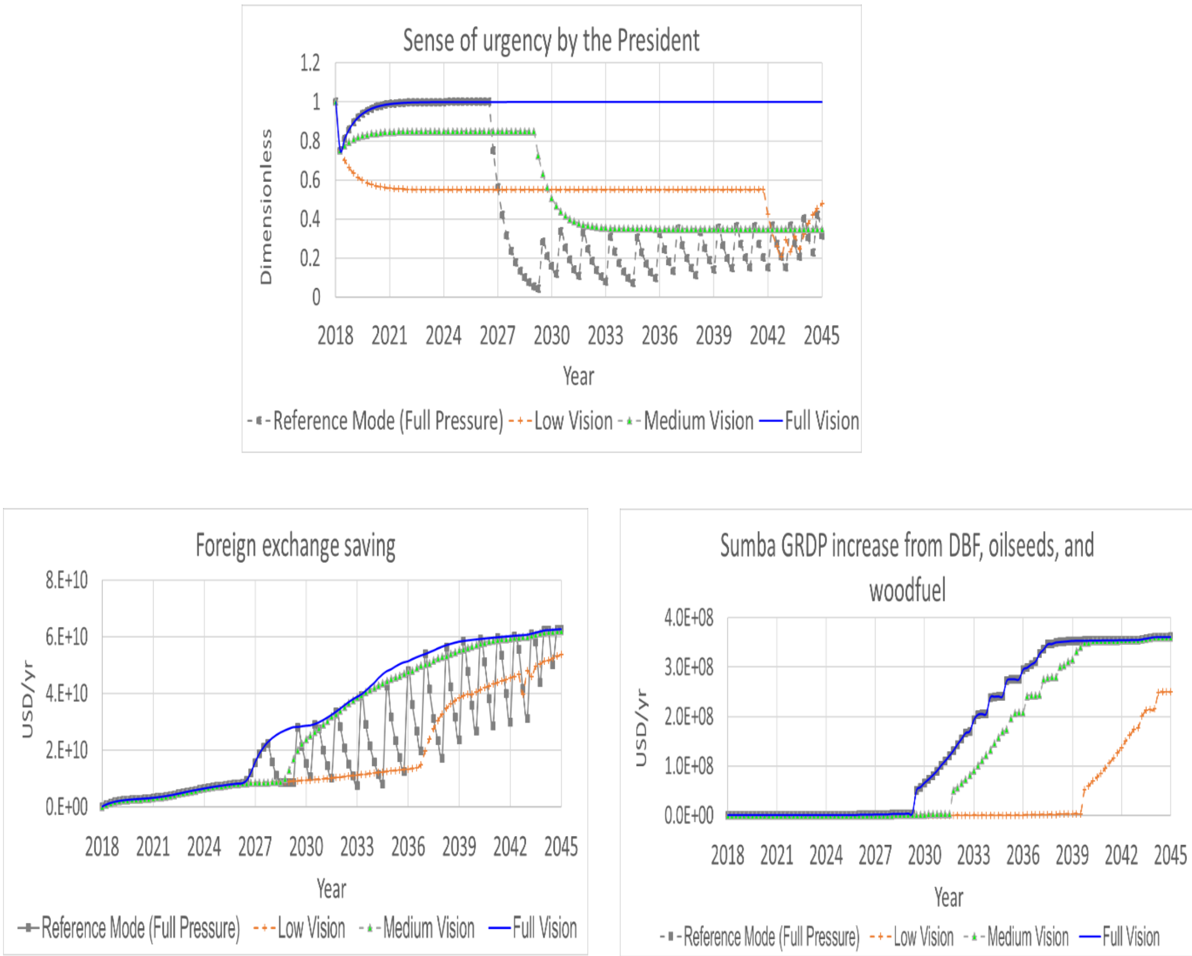


Fig. 8.13 Selected socioeconomic impacts across the low (LV), medium (MV), and full (FV) vision scenarios.

An increase in SU has positive impacts by increasing the Sumba GRDP from DBF, oilseeds and woodfuel (SGI). At a fixed WVS, an increase in future vision improves SGI.

GRDP 2017 (current market price) of East Sumba and Central Sumba was around USD 600 M/year BPSKSTM (2018); BPSKSTB (2018)). For the Reference Mode (FP Scenario) and the FV scenario, SGI was projected to reach USD 50 M/yr in 2030 when the DBF production starts, which is around 8% of GRDP in 2017. Then it increases sharply to USD 346 M/yr in 2037 or around 58% of GRDP in 2017. For the MV Scenario, it has–the same pattern and values but starts two years later. For the LV Scenario, it is ten years later and does not peak before 2045.

As for the impact to foreign exchange saving at a national scale, the utilization of marginal land for DBF production and use in Sumba island is a short-run effort which can increase the long-run local economy dramatically through GRDP increases from DBF, oilseeds and woodfuel.

Another important long-term impact is CO_2 emission reduction. The increase in SU increases CO_2 emissions reduction. At a fixed WVS, an increase in future vision increases CO_2 emissions reduction. For the Reference Mode (FP Scenario) and FV Scenario, CO_2 emissions reduction is projected to start in 2024 and reach 4.9 Mt CO_2e/year for Sumba and 248 Mt CO_2e/year nationally in 2038. Then it increases slightly to 5.2 and 261 Mt CO_2e/year in 2045 respectively when CO_2 reduction comes only from energy related use. For the MV Scenario, it has similar patterns and values but is delayed by two years. For the LV Scenario, it starts ten years later and reaches only 3.9 and 193 Mt CO_2/year respectively in 2045 (Fig. 8.14).

The national CO_2 emissions reduction through the strategy implementation in the FV Scenario is projected to contribute 101 Mt CO_2e/year by 2030, which equates to around 12% of the Indonesian NDC (Section 2.5.2 Environmental impacts).

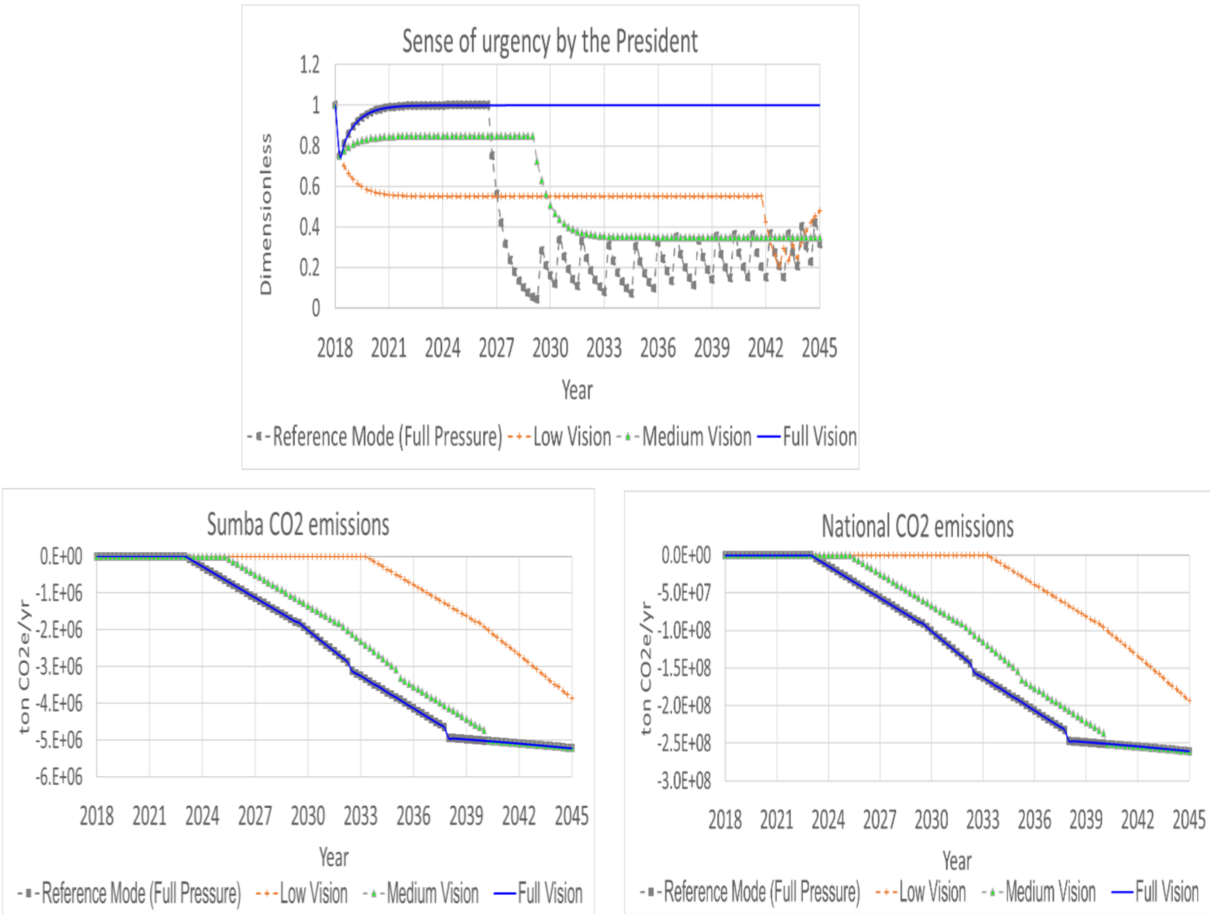


Fig. 8.14 CO_2 emissions across the low (LV), medium (MV), and full (FV) vision scenarios

8.4.1.3 Implications in planting delay across vision scenarios

Based on the simulation results, the key constraint is planting delay, generated through any delays in relevant stages from DBF technology readiness up to the first DBF commercial plant start-up.

Planting delay reflects the delay in planting a crop for DBF production after the conversion technology is ready. It is influenced by the sense of urgency by the President which is driven by pressure and vision. It is calculated as the difference between the required year to start planting and the actual year of commencing.

Equations that determine planting delay were explained in Section 7.6.4 and stated by Equation 7.22 and 7.23. The required year to start planting is calculated as the year when DBF technology commercially ready subtracted by duration since planting crop until the first harvest of oilseeds feedstock for the first DBF production plant. While the actual year of start planting is calculated as the year of the first harvest of oilseeds feedstock subtracted by the time from planting crop until the first harvest. The values of year variables were picked from the simulation results, and time from planting until first harvest is three years.

Fig. 8.15 shows the simulation results for times to start relevant stages in assessing the policy implications in planting delay, comprising technology technical readiness, Sumba developed marginal land area, Sumba oilseed feedstock production, and Sumba DBF production. Due to data limitation, the year when the technology is commercially ready is not endogenously generated by the system. Instead, it was calculated as simply adding the year of technical readiness by duration for preparing post-technical readiness, which is three years, based on an interview (Saparita, 2017).

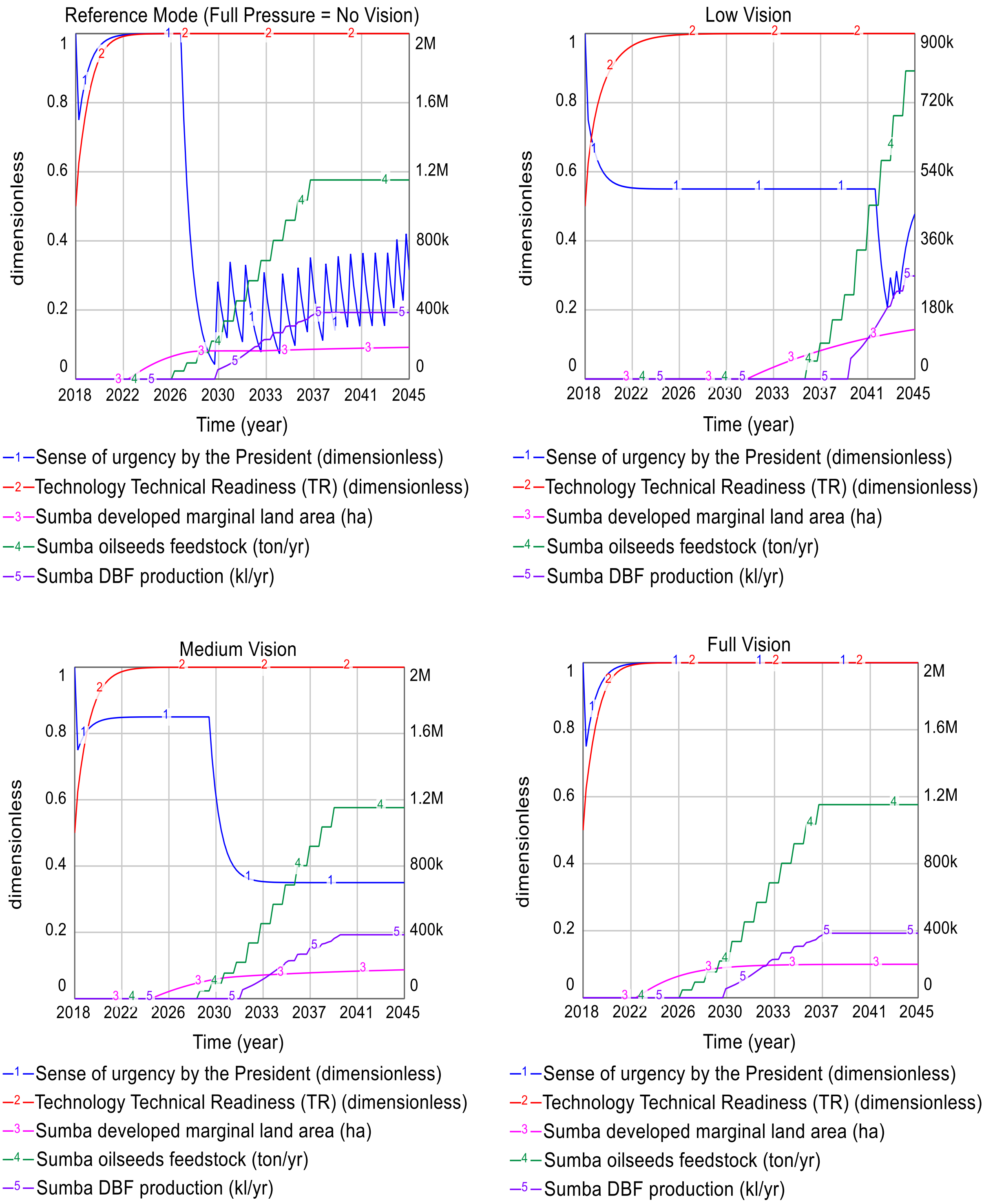


Fig. 8.15 Determination of planting delay across the low (LV), medium (MV), and full (FV) vision scenarios compared to Reference Mode

Fig. 8.15 shows that for the Reference Mode (FP Scenario) and FV Scenario, DBF technology is projected to be technically ready in 2023 and ready for commercial production in 2026. Meanwhile, using marginal land on Sumba for growing the biofuel crop is projected to start development in 2023. Hence Sumba oilseeds feedstock for DBF production is harvestable for the first time in 2026.

Applying equations 7.22 and 7.23, to execute the required year to start planting or to have oilseeds feedstock for the first DBF commercial production, planting crop on marginal land should ideally have been started in 2019. However, the actual planting is projected to start in 2023. Thus, the planting delay for the Reference Mode and FV Scenario is four years. These two scenarios result in the same planting delay because, given the assumptions, the SU level is generated by both scenarios at early year impacts to give the same start time of DBF production.

The same procedures were applied to the other vision scenarios (Table 8.5). From the simulation results, any planting delay is reduced by an increase in SU. The results of the LV Scenario and MV Scenario show that at fixed WVS, an increase in the future vision drives up and stabilizes SU, and hence reduces the planting delay. For the MV Scenario, the planting delay is five years or one year longer than for the FP Scenario and FV Scenario, compared with the LV Scenario where it takes ten years or six years longer.

Fig. 8.15 and Table 8.5 show that delays in DBF technology readiness lead to delays in utilising the marginal land developed area, and hence in oilseeds feedstock production, DBF production, and thus the liquid fuel self-sufficiency. Thus, SU in liquid biofuel implementation through utilization of marginal land and innovation in feedstock conversion technology is a critical factor because a delay in any of the earlier stages causes a delay in all subsequent stages of the liquid fuel self-sufficiency progress (Fig. 8.9).

An increase in SU decreases planting delay. However, SU in Reference Mode which is fully pressure-driven, fluctuates wildly. An increase in future vision stabilizes SU, while at a fixed WVS, it also drives up the SU.

Table 8.5 Policy implications across the low (LV), medium (MV), and full (FV) vision scenarios compared to Reference Mode

Parameters	Reference Mode / Full Pressure (FP) Scenario	Full vision (FV) scenario	Medium vision (MV) scenario	Low vision (LV) scenario
Crop rotation cycle (CRC)	15 yrs	15 yrs	15 yrs	15 yrs
Weight to vision (WVS)	0	1	0.5	0.5
Future vision power (FVS)	0	1	0.7	0.1
Vision influence to urgency = WVS*FVS	0%	100%	35%	5%
Pressure influence to SU = weight to pressure = (1-WVS)	100%	0%	50%	50%
SU = Vision + Pressure	100%	100%	85%	55%
Year when conversion technology technically ready	2023	2023	2023	2026
Year when technology commercially ready	2026	2026	2026	2029
Year of starting marginal land area development	2023	2023	2025	2032
Year of first harvest of oilseeds feedstock	2026	2026	2029	2037
Year of starting DBF production	2030	2030	2032	2040
Deisrable year to start planting	2019	2019	2021	2024
Actual year to start planting	2023	2023	2026	2034
Planting delay	4 yrs	4 yrs	5 yrs	10 yrs

8.4.2 Crop rotation cycle (CRC) scenarios (trading-off oil feedstock benefit and climate benefit)

8.4.2.1 Design of CRC scenarios

CRC affects oilseeds feedstock production and CO_2 emissions reduction in opposite ways. An increase in CRC increases the period of growing crops and hence offers more seasons for harvesting oilseeds during the crop's growth. On the other hand, an increase in CRC also increases the block area required for planting and hence the period of waiting until the area for each of the blocks is ready for growing the crop. In addition, the increase in CRC increases the time of waiting until harvesting woodfuel from the trees at the end of their productive life. Consequently, an increase in CRC reduces the speed of carbon sequestration by the crop on marginal land. Therefore, it is important to determine the optimum CRC through simulations on various CRC values, in order to trading-off oil feedstock benefit and climate benefit.

The CRC scenarios were simulated under full vision intervention which among the vision scenarios, resulted in the best system performance (Section 8.3.2.1). Three CRC scenarios were established: (i) oil feedstock benefit scenario (OBS); (ii) climate benefit scenario (CBS), and (iii) trade-off scenario (TOS) (Table 8.6).

Table 8.6 Design of CRC Scenarios: oil feedstock benefit scenario (OBS), climate benefit scenario (CBS), and trade-off scenario (TOS)

Scenario	Weight to vision (WVS)	Future vision power (FVS)	Crop rotation cycle (CRC)
Oil feedstock benefit scenario (OBS)	1	1	15
Climate benefit scenario (CBS)	1	1	5
Trade-off scenario (TOS)	1	1	10

OBS applies a CRC of 15 years which is the highest CRC in the structured model. CBS uses a CRC of 5 years which gives early oilseeds harvest. TOS applies a CRC of 10 years which is the median. The choices of CRC variations also considered pongamia crop growth characteristics with the oilseed harvest yields peaking at around the 8^{th} growth year (Murphy et al., 2012).

8.4.2.2 Implications across CRC scenarios

OBS results in the highest values over the simulation period for Sumba liquid fuel self-sufficiency, national liquid fuel self-sufficiency, and national liquid biofuel actual share (Fig. 8.16), but gives the lowest values for Sumba and national CO_2 emissions. On the other hand, CBS performs the least in liquid biofuel implementation but the best in CO_2 emissions indicators. Thus, TOS results in all the indicators having an optimum value in between the other two scenarios. This implies that ten years is the optimum CRC to gain the benefits of both oil feedstock productivity and climate mitigation.

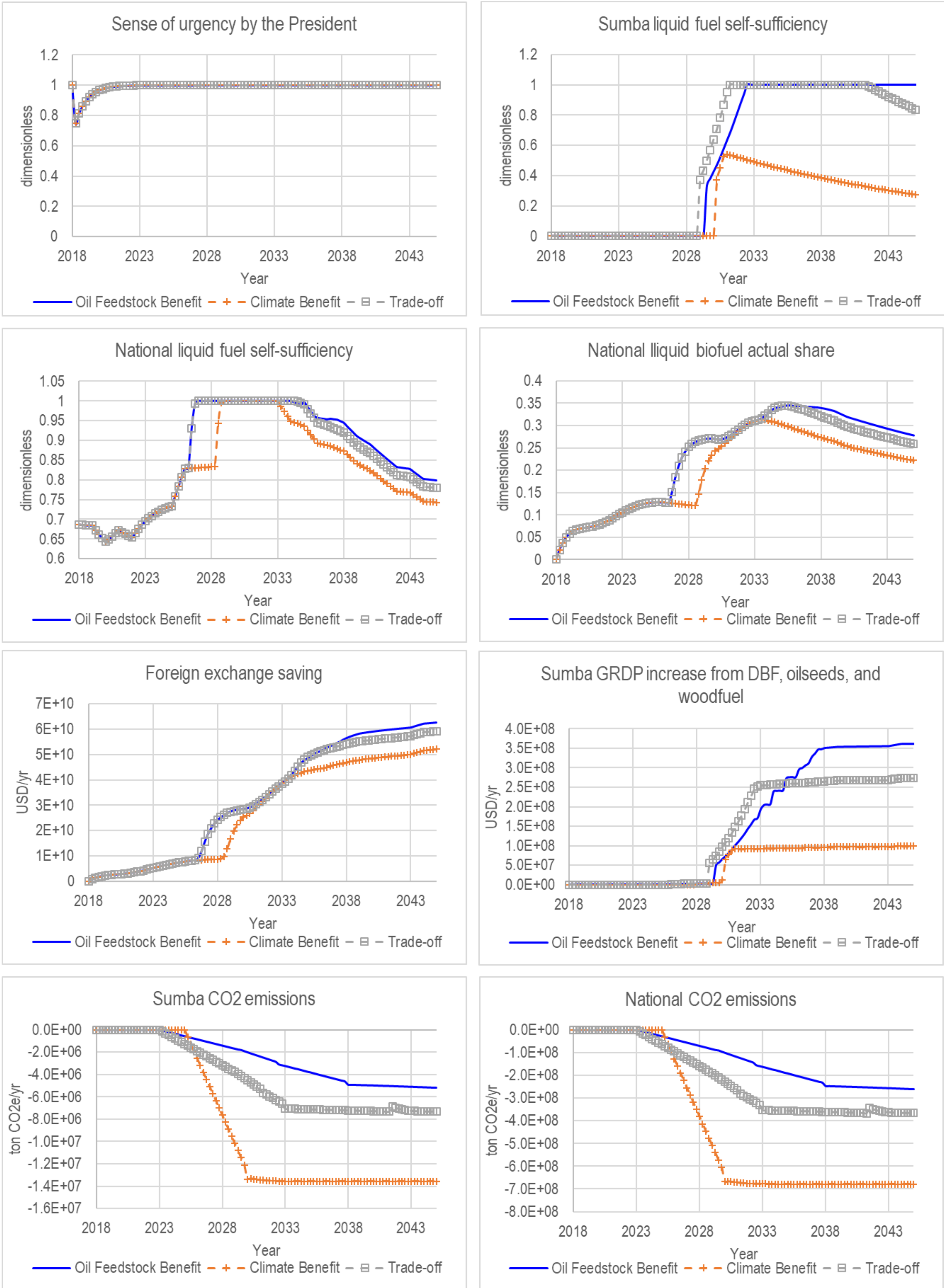


Fig. 8.16 Trading-off oil feedstock benefit and climate benefit through CRC scenarios: oil feedstock benefit scenario (OBS), climate benefit scenario (CBS), and trade-off scenario (TOS)

The TOS CRC of ten years shows the following performance factors compared with a 15 year CRC under the OBS:

- Sumba liquid fuel self-sufficiency peaks one year earlier. However, unlike OBS, which has a maximum performance up to 2045, TOS has a decline from 1 in 2041 to 0.84 in 2045.
- National liquid fuel self-sufficiency of TOS starts and peaks at similar pattern and values up to 2034, then decreases to 0.78 which is slightly lower than for the OBS in 2045.
- Both have a similar pattern of national liquid biofuel actual shares whereas for the TOS it reaches 0.26 in 2045, which is slightly lower than for the OBS.
- Foreign exchange saving of TOS reaches USD 62.7 billion/year or around 6% less than OBS in 2045.
- Sumba GRDP increases from DBF, oilseeds and woodfuel of the TOS is USD 274 million/yr or around 24% lower than OBS in 2045.
- National CO_2 emissions reduction of TOS is 367 Mt CO_2e/year or around 41% deeper which means better than OBS in 2045. In 2030, the value is 228 Mt CO_2e /year or 14% deeper than OBS and equal to around 27% of the Indonesian NDC by 2030 (Section 2.5.2 Environmental impacts).

Thus, lessons have been learned from comparing the scenario outputs as outlined in the following chapter 9.

CHAPTER 9
CONCLUSIONS AND RECOMMENDATIONS

9.1 Introduction

This chapter summarises the outputs from the model analyses. Sections 9.2 and 9.3 describe the contributions and findings; Section 9.4 provides policy recommendations; and Section 9.5 discusses the research limitations and provides recommendations for further research.

9.2 Contributions

This thesis:

- proposed a strategy for increasing liquid fuel self-sufficiency in Indonesia using marginal land to grow oilseed crops and deploying evolving conversion technology innovation to produce drop-in biofuel (DBF) in an integrated fashion; and
- developed a guiding framework (Chapter 3) using a systems approach and developed a model, *Assessment Tool of Biofuel Strategy through Utilization of Marginal Land and Innovation in Conversion Technology* (ABMIC) (Chapter 7) to test the framework.

Regarding system theory, this study provided a better understanding of the potential for DBF production by investigating the intrinsic properties between liquid fuel self-sufficiency, liquid biofuel implementation through marginal land-based feedstock, and conversion technology innovation, using a system dynamics approach.

Moreover, in the context of bioenergy sustainability, the study explicitly included the political dimension which differentiates it from other existing studies.

In the context of policy modelling, the study suggests determining a target for liquid biofuel shares of total liquid fuels that should be based on anticipated demand instead of historical data. Unlike a history-based demand target, a future-based demand target can be less affected by any price trend if it is accompanied with an anticipative pricing system to meet the liquid biofuel target volume.

Regarding policy analysis, the study developed scenarios to provide policy insights into increasing liquid fuel self-sufficiency through the proposed liquid biofuel strategy.

This is especially relevant to Indonesia and other countries that are highly dependent on liquid fuel imports but possess marginal land that potentially could grow energy crops. The study also provided insights for fulfilling the commitment of climate change mitigation through the National Determined Contribution (NDC) of Indonesia, and possibly also for other countries.

Built using a systems dynamics approach, the ABMIC model comprises several feedback loops including two invented for this study:

(i) the *sense of urgency by the President* (SU) loop which illustrates interdependency between SU and liquid biofuel implementation and

(ii) the loop which describes the dynamics of transition from oxygenated biofuel to drop-in biofuel, both involving palm oil feedstock, from the time when the DBF production technology is ready until the feedstock from the oil crops grown on marginal land becomes available.

Applying the systems dynamics approach, the ABMIC model can be used as a tool to enable policymakers better understand the complexity of the system for increasing liquid fuel self-sufficiency through the proposed biofuel strategy and to help them with a policy-making process such as in performing "what-if" analyses. The ABMIC model can be used in considering plans, strategies, and directions in improving liquid fuel self-sufficiency.

For Indonesia as a developing country, the ABMIC model is a user-friendly tool that can assist busy people and non-experts in policy-making, thanks to its transparency and flexibility in collecting and using data and information as well as being able to easily revising the structure as required.

9.3 Findings

From the assessments in previous chapters based on the research objectives, this study supported the hypothesis that if liquid biofuels are produced in Indonesia as low-carbon alternatives to petroleum fuels, a political element will critically affect the success of implementing a liquid biofuel strategy that includes marginal land use and conversion technology innovation to increase liquid fuel self-sufficiency, which in turn influences the political element itself. The main findings are highlighted as follow.

From the assessment of marginal land use for bioenergy (Chapter 4), criteria for suitable energy crop for marginal land in Indonesia were determined that have capabilities in oil production, fuelwood production, N_2 fixation, added values to non-oil parts of the crop, growth rates, and salt resistance. Based on these criteria, three crops were proposed, namely *Pongamia pinnata, Calophyllum inophyllum, Reutealis trisperma,* in priority order.

From the assessment of DBF production technology (Chapter 5), the study summarized potential technologies for DBF production in Indonesia, based on feedstock type, products characteristics, yield, reaction condition, current development stage, economic feasibility assessment, upgrading cost, and the constraints for commercialization. Based on these criteria, two priorities for DBF technology routes that use oil feedstock were proposed, namely decarboxylation of metal soap and hydrodeoxygenation. Both have been under development progress in Indonesia for several years (Chapter 5). Based on the technology characteristics and the current progress, the involved technologists and scientists stated that the only significant challenge in accomplishing the technical readiness and eventual commercialisation is the continuity of funding support which has been received intermittently from the government (Appendix D).

The case study of Sumba island emphasized the marginal land use issue (Chapter 6). Based on soil tests, generally this land would probably be suitable for growing *Pongamia sp.* as the preferred crop. However, before implementation, it is recommended to consider further on-site assessments as well as consider regulations regarding plantation type restrictions for each land category. Five important factors that can affect support for progressing marginal land development are: (i) infrastructure readiness; (ii) local government commitment; (iii) landowners' willingness to cultivate; (iv) land status clarity, and (v) local government interest around the "Sumba Iconic Island" program.

Through the modelling, the study demonstrated that the systems dynamics approach is suitable for assessing an integrated strategy for increasing liquid fuel self-sufficiency through marginal land use and biofuel conversion technology innovation. This methodology also confirmed the capability of the ABMIC model for addressing the transdisciplinary problem, flexibility needed in collecting and processing data and information, and transparency in generating results. The model showed its capability for assisting stakeholders to communicate and play specific roles in implementing the strategy. Thus, the ABMIC model can provide policy insights in implementing and evaluating the proposed strategy based on scenarios.

Validation tests showed that the ABMIC model is robust enough in generating system behaviours. The *usefulness test* confirmed from a survey that core potential model users found the model had high relevance, reliability, practicality, and importance. Two non-core potential users provided useful inputs for model improvement, to make it more accommodating of their specific interests such as inclusion of private business roles and as a research and technology planning tool. These suggestions provide opportunities for further research.

Simulations were carried out on the Reference Mode (baseline) and a set of scenarios designed to show how the system responds to a change in policy as follows.

- The ABMIC model showed that the sense of urgency by the President (SU) is the key leverage point in liquid biofuel implementation for increasing liquid fuel self-sufficiency in Indonesia. On the supply side, an increase in SU drives up DBF production by simultaneously affecting marginal land use for DBF feedstock and DBF technology innovation. On the demand side, an increase in SU increases the actual biofuel share of total national liquid fuels by setting an anticipative target for liquid biofuel production as well as a pricing system to absorb the liquid fuel targeted volume.
- SU has been driven responsively to pressures from the balance of trade and fuel price differences which fluctuate since they are determined by the volumes and prices of associated energy commodities. Scenarios were designed to simulate how SU affect the system's behaviours, and how SU and the system's performance respond to an intervention by future vision which is classified by the level of vision.
- Given the assumptions of the Reference Mode where SU is fully pressure-driven, the SU is projected at such a level that leads to a similar time to start DBF production as for the scenario where SU is fully vision-driven, and thus the liquid biofuel reaches self-sufficiency. However, the absence of a future vision in the Reference Mode causes the fluctuation in SU, and hence in the share of biofuel in the national liquid fuel demand. From the results of scenarios with vision, an increase in future vision accelerates the start time of DBF production as well as removes any fluctuations in biofuel actual share of national liquid fuel demand.

- The most important implication from the simulation results is that an increase in urgency (SU) reduces any delay in planting the oil crops which occurs between the actual start of planting and the required start to obtain feedstock for running the first DBF plant. A delay in marginal land preparation causes a delay in start time to plant the crop, which consequently causes a delay in oilseeds feedstock production, which leads to a delay in DBF production. Thus, each of the delays is accumulated and manifested in an overall delay in achieving liquid fuel self-sufficiency.
- The scenario-based simulation results provide policy insights to the decision-making process in the current system where DBF technology development is progressing while marginal land development for providing DBF feedstock has not been initiated. DBF production is vital in improving liquid biofuel implementation. Therefore, it is crucial to minimize delay in DBF implementation as it has huge impacts on the major Indonesian concerns around sustainable development such as foreign exchange saving, GRDP increase, and CO_2 emissions reduction.
- Although it was not modelled in detail, the short-run effect in investment for DBF technology has long-run effects in improving the Indonesian sustainable development at much greater values, as mentioned in the previous paragraph.

9.4 Policy recommendation

The strategy of drop-in biofuel (DBF) production integrated with using marginal land to grow oilseed crops for biofuel production, thereby increasing liquid fuel self-sufficiency for Indonesia, is better than staying with the current use of oxygenated biofuel production using conventional palm oil feedstock.

The strategy implementation allows much higher capacity in improving national energy self-sufficiency, and thus more positive impacts in foreign exchange saving, GRDP, and CO_2 emissions reduction. Furthermore, the proposed strategy can help smooth the transition of vehicle fuels from liquids to electricity (Chapter 2). Without non-oil based fuels to displace the loss of indigenous oil supplies, the Indonesian economy could come under stress due to the increase in trade balance deficit while limiting the financial capacity (Chapter 7). In avoiding the risk of economic collapse, it is fundamental to accelerate DBF production, preferably using marginal land as well as indigenous conversion technology.

In optimizing liquid fuel self-sufficiency through the proposed strategy, any delay should be minimized, because a delay in any of the earlier stages will cause an accumulated delay in later stages. Also, in a cross-sectoral problem, the delay in any of the involved sectors leads to delays across whole sectors. In order to minimize delays, the sense of urgency by the President who has the upmost cross-sectoral authority, should be sufficient to drive forward the efforts in liquid biofuel implementation (Chapter 2).

In minimizing delays, there are two critical parts where the sense of urgency by the President (SU) plays a role:

- setting apart as early as possible the investment for DBF technology innovation until the technology is commercially ready, as the short-run effect in investment for DBF technology development has a long-run effect and much greater values in foreign exchange saving, GRDP increase, and CO_2 emissions reduction; and
- giving early instructions to start marginal land cultivation for growing oil-bearing energy crops. Efforts should be made urgently until DBF commercial production starts and grows in order to minimize any risks in future trade balance deficits.

To increase and stabilize SU to minimize delays, it is recommended that the future vision should be activated and maximized. In contrast, fluctuated pressure from the balance of trade and fuel price differences used to dominate SU should be minimized.

In generating SU with minimal fluctuation potential, the future vision of Indonesia to become a sovereign country, based on the 1945 Constitution preamble, needs to be applied all the time. In supporting DBF technology readiness, the future vision allows setting apart the anticipative investment for DBF technology innovation. In supporting marginal land use for growing energy crops, delays in planting oilseed crops in anticipation of running the first DBF commercial plant are minimised. In increasing the national share of liquid biofuels, the future vision allows setting the target based on anticipative or future-based demand.

In realizing the future vision in next few years, specific proposals are recommended to the President, including:

- Building a DBF demonstration plant.
- Developing marginal land area for growing energy crop.
- Training the farmers how to grow and use pongamia on poor land.

- Undertaking field trials to ensure this crop will grow satisfactorily on a type of degraded land.

The simulation results showed that by 2045, palm oil as the existing feedstock for liquid biofuel and pongamia oil as the preferable feedstock, together will not be sufficient to meet the Indonesian liquid fuel demand. Therefore, other potential feedstocks such as ligno-cellulosic biomass and algae should be investigated, along with developing suitable conversion technologies for DBF production, in order to maximize national liquid fuel self-sufficiency.

9.5 Limitations and recommendations for further research

The ABMIC model was developed to meet the study objectives. However, the model still has some data-related limitations which were not fully resolved as outlined below. Thus, the model can be further improved through future research.

The reasons for the current limitations in the ABMIC model are as follows.

- Inclusion of integrated aspects of economic, environmental, social and political issues, and coverage of the national level has sacrificed the model depth in capturing representative variables.
- DBF production has not existed commercially, so some data were taken as assumptions from similar conditions (Chapter 5).
- Some parameter values, such as data of oil and gas exports and imports used in the balance of trade calculation, were drawn from BPPT (2018), (IEA, 2017b) and WorldBank (2018), rather than being generated by the model.
- Variable quantifications, for instance the variables to determine support for development of marginal land, were often found in the model as they are also common in policy modelling.
- Model validation had limitations due to time restrictions and participants availability.

Specific limitations in the ABMIC model and recommendations for further research in dealing with them are outlined below:

- In the calculation of the balance of trade, price and volume of associated energy commodities, non-oil and gas export value, and non-oil and gas import values were treated as exogenous variables, in forms of projection time series as found in the literature. It is possible to treat non-price variables such as volumes of crude oil, oil fuel, natural gas, LPG, and palm oil as endogenous variables to improve the projection quality. Based on the ABMIC model purpose, this is not highly important because the balance of trade is inherently fluctuating, which is why future vision is required in improving the sense of urgency.

- In the calculation of the liquid fuel import demand, the model quality could be improved by treating Sumba liquid fuel demand, national liquid fuel demand, and national oil fuels production, as endogenous variables. The accuracy could also be improved by including oxygenated biofuels other than palm oil biodiesel, and differentiating between DBF types.
- In the calculation of production and prices of oil feedstock from marginal land, determination of variables such as the pongamia crop growth rate, oilseeds yield, Sumba marginal land available area, and marginal land feedstock management (MFM) can be improved.
- The accuracy of crop growth and oilseeds yield (which were adopted from research in another country (Chapter 4)) could be improved by using a range which applies a correction factor based on soil and climate conditions. Also, the model could accommodate heterogenous crops with each type based on land type and condition, interest, and impact.
- In calculating the oil feedstock production potential, the available area of marginal land on Sumba was estimated based on geographical general condition and interviews. This could be improved using spatial dynamics. At the national level, it could be better estimated by involving islands in addition to Sumba and disaggregating other islands, instead of using a single multiplier for national area based on the local area of Sumba. Consequently, the specifications of variables which support the marginal land development rate might also be different in other islands.
- Marginal land feedstock management (MFM) is a type of policy parameter that covers feedstock cultivation, harvesting, collection, storage, distribution and price. This in turn influences DBF production and consumption and liquid biofuel shares. In this study, MFM was set to 1 as the baseline for maximum oil feedstock

production, which means that the management of feedstock grown on the marginal land is at a maximum.

- In maintaining liquid biofuel supply and demand, it is important for feedstock pricing to be controlled as part of feedstock management. In this study, pongamia oil feedstock cost was assumed to be free from demand influence as it was assumed to be well-controlled by the government. This would dominate marginal landownership and play a major role in the cultivation and commitment of feedstock produced for energy purpose (Chapters 4 and 6). To see how the system responds to changes in MFM, and hence improves the model quality, it is recommended to create functions of MFM effects on associated indicators such as pongamia feedstock production and pongamia cost growth rates.
- Palm oil costs, which were roughly estimated based on current trends, could be improved by building a function of palm oil demand effect to palm oil cost.
- The model for marginal land preparedness can be improved by specifying a function of SU effects to corresponding support on Sumba marginal land development rate such as for infrastructure readiness, strengthening commitment of the local government especially the Regent, Sumba Iconic Island (SII) programme, income guarantee, and understanding by landowners.
- The model for DBF technology readiness could be improved by dividing into different phases; by building functions of SU effects to support DBF technology readiness, and by expanding the model of investment that influences DBF technology readiness to describe the dynamics of trade-off between short-run negative effect in investment and long-run advantages in foreign exchange savings and GRDP increase.
- To represent more accurately the fluctuation of actual shares of national liquid biofuel in line with the SU in the Reference Mode, a function effect of the liquid biofuel demand to liquid biofuel supply could be built, thus adding a new feedback.
- To improve the accuracy for the DBF production model, further research could be carried out by involving islands outside of Sumba and providing a disaggregation of the DBF production model into various DBF plant units. These improvements would also increase accuracy in liquid fuel import demand calculations.

- The model for DBF production costs from marginal land feedstock could be made more representative by applying a range of by-product revenues to cover a wider possible range.
- The model for CO_2 emissions reduction could be made more representative by applying a range of CO_2 emission and sequestration factors to cover a wider possible range of CO_2 emissions reduction potentials.
- For a more in-depth assessment, further exploration and investigation could be carried out in the area of SU structure in describing political sustainability, and the transition from oxygenated biofuel to drop-in biofuel.
- The quality of variable quantification could be improved by increasing the number of respondents and the amount of information.
- Validation of the model was adequate to confirm the research objectives. However, it could be improved through conducting more interviews with more engaged stakeholders, for example, when validating behaviours and in the quantification of the soft variables.

With these existing limitations, the ABMIC model can be considered to be a preliminary version. The overall quality could be improved through refining and improving data as well as getting more involvement and feedback from policy end-users.

The ABMIC model can be applied in other sectors. For example, for assessing transition to a bioeconomy which is now emerging to support sustainable development in several biomass-rich countries (Chapter 2). An investigation could be carried out to predict when a bioeconomy can substantially progress in Indonesia, being a biomass-rich country, or on the interdependence between the upstream and downstream stages within the bioeconomy industry. Unlike this study, the purpose of such modelling is "point of prediction" that will require more detail of data, equation and validation. Moreover, the structure of the sense of urgency by the President in the ABMIC model could also be modified and adopted for an assessment of non-bioenergy sectors, such as other renewable energy, food, education, and health.

Despite the limitations listed above, given the assumptions, the ABMIC model was sufficient for meeting the purpose of the study to provide insights into assessing the integrated strategy for increasing liquid fuel self-sufficiency in Indonesia through marginal land-use and technology innovation. This study shows how assessment of innovative strategy in improving liquid fuel security can be integrated with a systems dynamics model.

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APPENDICES

APPENDIX A : LETTERS AND FORMS

A1: Information Sheet (translated from Bahasa Indonesia)

"Model for sustainable bioenergy planning that considers marginal land use and technology readiness"

INFORMATION SHEET

You are invited to participate in a PhD research that models sustainable bioenergy planning that considers marginal land use and technology readiness, as stated in the title. This reasearch is conducted by a PhD student at Massey University New Zealand:

Maslan Lamria (the researcher's name~~)~~

School of Engineering and Advanced Technology

Massey University, Palmerston North, New Zealand

Tel: +64 [redacted] (NZ); +62 [redacted] (ID)

Email: [redacted]

Project Description

Indonesia is highly dependent on oil fuels imports. On the other hand, Indonesia has large area of marginal land that is potential for growing liquid biofuel feedstock. Also, Indonesia is developing a technology to produce drop-in biofuel that has equivalent characteristics to petroleum fuels and suitable for production in small islands.

There has never been found a model for sustainable bioenergy planning that considers marginal land use and future technology availability. In developing the model we should look into the system's structure to explore policies that can support the determined strategy and to analyse feedbacks between the interdependent components, which can be done using a systems dynamics approach as carried out in this reseach.

Participant Identification and Recruitment

The participants were identified by reviewing expertise or professional positions that are relevant to this research. For sending the invitation, the participant was contacted for the first time either by email or phone or posted-mail.

The number of participants is expected around twenty comprising technical experts and policymakers to provide opinions for the developed model and/or assessent on the model appropriateness.

Compensation for cost directly related to the participation will be provided for an interview/discussion that is held at least for half-day long.

Project Procedures

Once you decide to participate, you will be asked to sign Consent Form separate from this information sheet. Then you will be asked for alternative schedules for the interview/discussion. A list of questions or a guideline will be provided when necessary. In case a follow-through is required for a clarification or providing more information, it will be conducted either by phone talk or additional meeting or email according to the participant's availability.

The interviews/discussions for this research show no financial nor role conflict of interest.

Data Management

Data and information collected from the interview/discussion will be used only for this research where the results will not show your individual name, but only your generic position and your institution when required for citation, such as an energy expert at a state university. The results can be published or presented in a journal, conference or seminar. The interview/discussion records will be storaged as long as related to this research (unless the participant thinks differently) and accessable only by the researcher, the research supervisors, and the recorded participants.

The researcher will guarantee the confidentiality of recorded information according to the law although an absolute protection is impossible to provide.

Participants' Rights

You are under no obligation to accept this invitation. If you decide to participate, you have the right for:

- decline to answer any particular questions;
- withdraw from the study (with a notification in advanced and a strong reason);
- ask any questions about the study at any time during participation;
- provide information on the understanding that your name will not be used unless you give permission to the researcher;
- be given access to a summary of the project findings when it is concluded.
- Request for having the recorder turned off anytime during the interview/discussion.

Project Contacts

Should you have further questions regarding this project from now on and afterwards, you can contact either the researcher or the supervisor as follow:

The researcher:

Maslan Lamria

School of Engineering and Advanced Technology

Massey University, Palmerston North

Tel: +64 [redacted] (NZ); +62 [redacted] (ID)

Email: [redacted]

Main Supervisor:

Prof. Ralph Sims

School of Engineering and Advanced Technology

Massey University, Palmerston North

Tel: +64 6 350 5574

Email: r.e.sims@massey.ac.nz

Committeee Approval Statement

"This project has been evaluated by peer review and judged to be low risk. Consequently, it has not been reviewed by one of the University's Human Ethics Committees. The researcher(s) named above are responsible for the ethical conduct of this research.

If you have any concerns about the conduct of this research that you wish to raise with someone other than the researcher(s), please contact Dr Brian Finch, Director, Research Ethics, telephone 06 356 9099 x 86015, email humanethics@massey.ac.nz".

Thank you for considering to participate in this research

A2: Invitation letter templates (translated from Bahasa Indonesia)

Template of invitation letter
Focus group on DBF technology

Dear …………….,

I am a PhD student in Sustainable Energy at Massey University, New Zealand, who is also an on-study assignment employee of the Ministry of Energy and Mineral Resources.

In this research that models sustainable bioenergy planning that considers among others the readiness of drop-in biofuel technology which is suitable for Indonesia using a systems dynamics approach, I need data and information through interviews/discussions with technical experts and policymakers.

I would like to invite you to participate in a discussion about drop-in biofuel technology which is under development at Institut Teknologi Bandung, at:

Time : Monday, 28th November 2016, 14.30 – 16.30

Place : Area of the laboratory of Chemical Reaaction Engineering and Catalysis, Labtek X ITB (tentative)

The Information expected from the discussion about the drop-in biofuel technology include:
- The desired performance;
- Technical and financial progress;
- Technical and financial projection up to commercially ready.
- Conditions and factors that can either accelerate or retard the progress.
- Identification of policies that influence the progress at pilot, demonstration and commercial scale.
- Estimation of economic assessment.

Attached the Information Sheet as the invitation for your consideration to participate. Your contribution will be very beneficial for this research as well as the follow-up in the Indonesian renewable energy development.

If you will to participate, please inform me by email. Then you can sign the Consent Form which is returned via email or on the day-D before the discussion starts (the form will be provided).

Thank you very much for considering a participation in this research.

I look forward to hearing from you.

Yours sincerely,

<u>Maslan Lamria</u>

Email: [redacted]

Phone/SMS/WA: +[redacted] *(Indonesia)*

+[redacted] *(New Zealand)*

Template of invitation letter

Focus group on policy

Dear ……………,

I am a PhD student in Sustainable Energy at Massey University, New Zealand, who is also an on-study assignment employee of the Ministry of Energy and Mineral Resources.

In this research that models sustainable bioenergy planning that considers among others the readiness of drop-in biofuel technology which is suitable for Indonesia using a systems dynamics approach, I need data and information through interviews/discussions with technical experts and policymakers.

I would like to invite you to participate in a *Focus Group Discussion (FGD)*, at:

Time	: Thursday, 1st December 2016, 8.00 – 12.00
Place	: Meeting room of the Centre for Research on Energy Policy ITB, PAU Building 3rd Floor, Jl Ganesha 10 Bandung.
Agenda	: gathering inpits from the experts toward the developed *system dynamics* model.

Attached the Information Sheet as the invitation for your consideration to participate. Your contribution will be very beneficial for this research as well as the follow-up in the Indonesian renewable energy development.

If you will to participate, please inform me by email. Then you can sign the Consent Form which is returned via email or on the day-D before the discussion starts (the form will be provided).

Thank you very much for considering a participation in this research.

I look forward to hearing from you.

Yours sincerely,

Maslan Lamria

Email: [redacted]

Phone/SMS/WA: +[redacted] *(Indonesia)*

+[redacted] *(New Zealand)*

A3. Interview Guideline (translated from Bahasa Indonesia)

INTERVIEW GUIDELINE

Interviewee name : …………………

Place : …………………

Time : ………………….

A. Background

Indonesia is highly dependent on oil fuels imports. On the other hand, Indonesia has large area of marginal land that is potential for growing liquid biofuel feedstock. Also, Indonesia is developing a technology to produce drop-in biofuel that has equivalent characteristics to petroleum fuels and suitable for production in small islands.

There has never been found a model for sustainable bioenergy planning that considers marginal land use and future technology availability. In developing the model we should look into the system's structure to explore policies that can support the determined strategy and to analyse feedbacks between the interdependent components, which can be done using a systems dynamics approach as carried out in this researach.

B. Researach aim and objectives
   a. Aim:

      To explore the system of Indonesian bioenergy planning that considers marginal land use and appropriate technology readiness, as parts of the bioenergy sustainability, to identify the structural attribute that has the most significant impacts to policy.

   b. Objectives:
      i. To better understand the sustainable bioenergy planning that considers marginal land use and appropriate technology readiness.
      ii. To develop the sustainability indicator that is relevant with the sustainable bioenergy planning that considers marginal land use and appropriate technology readiness.

C. The System Dynamics Model
   a. High-level diagram
      The high-level diagram is shown in Fig. 1. A print-out will be provided.

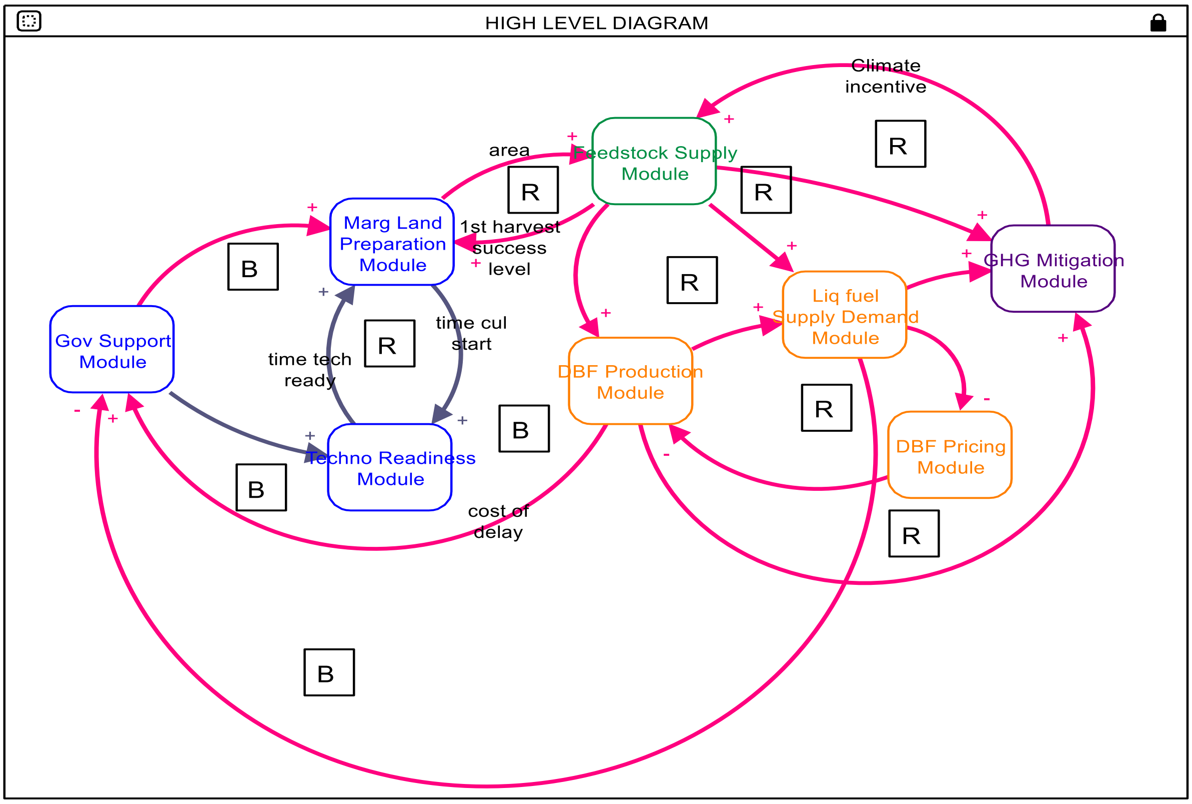


Fig. 1. *High-level diagram*

b. Details of the model structure for each module will be presented with an emphasize on particular parts to be commented. A print-out will be provided.
c. Scenarios and the simulation results will be presented.
d. You will be asked for your opinion and inputs for the model appropriateness, especially in the modules:
   i. …….
   ii. ……..

D. Analysis/recommendation for policy

*******Thank you very much for your participation *******

A4: Participant Consent Forms (provided by Massey University)

PARTICIPANT CONSENT FORM - INDIVIDUAL

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I agree/do not agree to the interview being sound recorded.

I agree/do not agree to the interview being image recorded.

I wish/do not wish to have my recordings returned to me.

I wish/do not wish to have data placed in an official archive.

I agree to participate in this study under the conditions set out in the Information Sheet.

Signature: .... **Date:** ....

Full Name - printed ....

PARTICIPANT CONSENT FORM - FOCUS GROUP

I have read the Information Sheet and have had the details of the study explained to me. My questions have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I agree not to disclose anything discussed in the Focus Group.

I agree to participate in this study under the conditions set out in the Information Sheet.

Signature: .... **Date:** ....

Full Name - printed ....

APPENDIX B: SOIL TEST RESULT

B1: Laboratory soil test result for Sumba marginal land

LABORATORIUM DEPARTEMEN ILMU TANAH DAN SUMBERDAYA LAHAN
FAKULTAS PERTANIAN IPB
Jl. MERANTI, KAMPUS IPB DARMAGA BOGOR 16680, Telp. (0251) 8627792, Fax. (0251) 8629358

LAPORAN HASIL PENGUJIAN
No.345/LHP/Lab DITSL/VIII/2016

NAMA PENGIRIM : [illegible]
ALAMAT PENGIRIM : Jl. Cisaranten Wetan IV No.58, Bandung
TANGGAL KIRIM : 6 Juni 2016
TANGGAL SELESAI : 11 Agustus 2016

LOKASI SAMPEL :
JUMLAH SAMPEL : 6 (Enam)
JENIS SAMPEL : Tanah

No. Lab	No. Lapang	pH 1:5		Walkley & Black	Kjeldahl	Bray I	HCl 25%	*N* NH_4OAc pH 7.0					KB	*N* KCl		DTPA				Tekstur (Metode Pipet)		
		H_2O	KCl	C-org	N-Total	P	P	Ca	Mg	K	Na	KTK		Al	H	Fe	Cu	Zn	Mn	Pasir	Debu	Liat
				..(%)..	..(%)..	...(ppm)...		..........(cmol$^{(+)}$/kg)..........					..(%)..	...(cmol$^{(+)}$/kg)...		...(ppm)...				........(%)........		
FA 0087	CD	6.92	6.14	3.63	0.27	13.45	50.36	66.25	0.69	0.68	0.55	41.60	100.00	tr	0.10	16.81	0.92	0.47	3.04	6.26	40.68	53.06
FA 0088	HP 1	7.29	6.24	4.42	0.32	13.82	107.91	98.51	3.68	0.95	0.80	45.56	100.00	tr	0.10	7.15	1.96	1.67	10.91	26.72	34.78	38.50
FA 0089	HP 2	7.52	6.42	1.81	0.17	4.59	21.58	56.01	1.78	0.17	0.70	17.43	100.00	tr	0.10	3.47	1.15	0.38	1.51	47.56	33.26	19.18
FA 0090	LM	7.11	6.31	12.24	0.41	11.65	176.26	85.54	4.29	0.46	0.72	67.75	100.00	tr	0.10	15.75	1.70	2.48	29.54	7.52	51.20	41.28
FA 0091	LP	7.48	6.65	3.35	0.28	12.55	154.65	59.32	1.28	0.68	0.77	59.83	100.00	tr	0.10	4.67	1.39	0.38	10.45	23.69	40.77	35.54
FA 0092	PJ	7.50	6.70	2.13	0.18	9.11	34.17	85.23	5.19	0.18	0.42	21.39	100.00	tr	0.10	6.22	0.44	1.00	8.36	52.80	32.72	14.48

Keterangan:
tr: tidak terukur

Bogor, 11 Agustus 2016
Koordinator Laboratorium
Departemen Ilmu Tanah dan Sumberdaya Lahan
Fakultas Pertanian IPB

LABORATORIUM
Departemen Tanah
Fakultas Pertanian
Institut Pertanian Bogor

Dr Ir Arief Hartono, M.Sc.agr.

Catatan :
1. Hasil pengujian hanya berlaku untuk sampel yang diuji

Halaman 1/1

B2: Laboratory soil test result of Parung Panjang site

SEAMEO BIOTROP
SERVICES LABORATORY
Jl. Raya Tajur Km. 6, P.O. Box 116, Bogor, Indonesia
Phone : 62-251-357175 Fax : 62-251-357175
Website : http://www.biotrop.org email : services. Lab@biotrop.org

KAN
LP-221-IDN

LEMBAR HASIL PENGUJIAN
TEST RESULT

No. Order / *Request Number* : 253/TT/II/2016
No. Contoh / *Sample number* : *609*
Halaman / *Page* : 2 dari/*of* 2

No.	Kode Contoh	*pH (1 : 1) SNI 03-6787-2002		*C Org SNI 13-4720-1998 (Walkey & Black)	*N Total SNI 13-4721-1998 (Kjeldahl)	Rasio C/N	*P_2O_5 tersedia SL-MU-TT-05 (Bray I/II)	Kation-kation dapat ditukar dan KTK (SL-MU-TT-07 c (Ekstrak Penyangga NH_4OAc 1,0 N pH 7,0))						KB	[illegible]		[illegible]		
		H_2O	$CaCl_2$					*Ca	*Mg	*K	*Na	Total	KTK		Al^{3+}	H^+	[illegible]	[illegible]	[illegible]
				%	%		ppm	cmol/kg						%	[illegible]	[illegible]	%	%	%
609	Parung Panjang	4.3	3.8	2.29	0.37	6	8.9	5.99	12.89	0.26	0.23	19.38	27.90	69.45	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Keterangan :
- Contoh uji dihitung terhadap contoh kering 105°C
- cmol/kg ≈ me/100g
- * Telah terakreditasi oleh KAN dengan No. LP-221-IDN
- **Jenis contoh = Tanah Lokasi Parung Panjang**

Bogor, [illegible] April 2016
Manajer Mutu
[illegible]
NIP. [illegible]

BIOTROP

LEMBAR HASIL PENGUJIAN

TEST RESULT

253/TT/II/2016
609
2 dari/*of* 2

*C Org	*N Total	Rasio C/N	*P_2O_5 tersedia	Kation-kation dapat ditukar dan KTK (SL-MU-TT-07 c (Ekstrak Penyangga NH_4OAc 1,0 N pH 7,0)						KB	Al-H_{dd} SL-MU-TT-09 (Ekstrak KCl 1N)		Tekstur 3 Fraksi SL-MU-TT-10 (Pipet)		
SNI 13-4720-1998 (Walkey & Black)	SNI 13-4721-1998 (Kjeldahl)		SL-MU-TT-05 (Bray I/II)	*Ca	*Mg	*K	*Na	Total	KTK		Al^{3+}	H^+	Pasir (50µ - 2mm)	Debu (2µ - 50µ)	Liat (0.2µ - 2µ)
%	%		ppm	cmol/kg						%	me/100g	me/100g	%	%	%
2.29	0.37	6	8.9	5.99	12.89	0.26	0.23	19.38	27.90	69.45	9.75	1.83	28.8	13.5	57.7

kering 105°C

an No. LP-221-IDN
g Panjang

Bogor, 19 April 2016

Manajer Mutu

BIOTROP

BSc

APPENDIX C: INTERVIEWS OF SUMBA MARGINAL LAND

Aim: to identify what factors might be supports and barriers for utilization of marginal land for growing energy crop.

Procedures from identification up to completing data and information collection:
Each of the participants was sent an invitation letter and an information sheet about the research and their participation. The interview meeting started with a presentation about the research. The questions and responses were open while sticking to the aim of interview to get useful information in building the model, as described in Chapter 4 and 6.
The participants consisted of six government officials and three private landowners that consisted of:

- The government officials:
  - Head for Forestry Agency, East Sumba (interview date: 30th May 2016)
  - Deputy Head for Energy Agency, East Sumba (interview date: 30th May 2016)
  - Head for Land Tenure Management, East Sumba (interview date: 30th May 2016)
  - Deputy Head for Forestry Agency, Central Sumba (interview date: 1st June 2016)
  - Head for Energy Agency, Central Sumba (interview date: 1st June 2016)
  - Regent's Advisor on Development Affairs, Central Sumba (interview date: 2nd June 2016)
- The three private landowners were interviewed on 30th May 2016.

APPENDIX D: FOCUS GROUP OF DBF TECHNOLOGY

Date: 28th November 2016

Place: ITB Campus, Bandung, Indonesia

Aim: to identify the most important factor that determines the progress of DBF technology development up to commercially ready.

Procedure:

Each of the participants was sent an invitation letter and an information sheet about the research and their participation. The meeting started with a presentation about the research and the high-level diagram of the developed model. Then the participants were pleased to discuss by themselves about important policy aspects to be considered in developing the model. The participants can ask any questions about the research and their participation since before the meeting was held.

All the participants were the researchers in the DBF Technology Group as listed in following table:

No	Name	Designation
1	Prof. Dr. Subagjo	The most senior in the research of hydrodeoxygenation technology for DBF production. Professor in chemical reaction engineering and catalysis at ITB.
2	Dr. Tatang H. Soerawidjaja	The most senior in the research of metal soap decarboxylation technology for DBF production. Associate Professor at Chemical Engineering Department ITB.
3	Dr. IGBN Makertihartha	Senior in the research of hydrodeoxygenation technology for DBF production. Associate Professor at Chemical Engineering Department ITB.
4	Godlief Fredrik Neonufa	Doctoral researcher in the metal soap decarboxylation technology for DBF production
5	Meiti Pratiwi	Doctoral researcher in the metal soap decarboxylation technology for DBF production
6	Endar Puspawiningtyas	Doctoral researcher in the metal soap decarboxylation technology for DBF production
6	Budiyanto	Doctoral researcher in the hydrodeoxygenation technology for DBF production

APPENDIX E: FOCUS GROUP OF POLICY

Time: 1st December 2016

Place: ITB Campus, Bandung, Indonesia

Aim: to capture policy ideas from cross-sectoral participants in developing the model.

Procedure:

Each of the participants was sent an invitation letter and an information sheet about the research and their participation. The meeting started with a presentation about the research and the high-level diagram of the developed model. Then the participants were pleased to discuss by themselves about important policy aspects to be considered in developing the model. The participants can ask any questions about the research and their participation since before the meeting was held.

List of participants:

No	Name	Designation
1	Prof Sigit Hardwinarto	Adviser to Minister of Energy and Mieral Resources Professor in forestry science at Tanjungpura University
2	Hudha Wijayanto	Official at the Directorate of Bioenergy, Ministry of Energy and Mineral Resources
3	Dr Dewi Yuliani	Official at the Energy Agency of West Java Province. Faliar with systems dynamics modelling.
4	Dr Ira Nurhayati Dj	Director for Research and Development System at the Ministry of Research, Technology and Higher Education
5	Dr. Muhammad Tasrif	Expert in systems dynamics modelling and Indonesian policy analysis. Research advisor at the Centre for Research on Energy Policy at ITB
6	Dr. Arsegianto	Research advisor at the Centre for Research on Energy Policy at ITB. Familiar with systems dynamics modelling.
7	A. Taufik	Researcher at the Centre for Research on Energy Policy at ITB. Familiar with systems dynamics modelling.
8	Dr. Henriette Imelda	Representative from a non-governmental organization
9	Adi Kristian	Representative from a bioenergy business enterprise

APPENDIX F: MODEL FACE VALIDATION

Aim: To get opinion about logical assessment on the "sense of urgency by the President" structure.

Procedure:

Each of the participants was sent an invitation letter and an information sheet about the research and their participation. After accepting the invitation, the participants were sent the interview guideline. The meeting started with a presentation about the research and the modelling results, then the participant was asked about their opinion. The participants can ask any questions about the research and their participation since before the meeting was held.

All participants hold PhD degree by research that used systems dynamics methodology:

1. Dr Rachmini Saparita (interview at Bandung, 11th May 2017)
   Professional description:

   - Researcher at the Indonesian Institute of Sciences, particularly in implementation of appropriate technology in rural areas.

2. Dr Arsegianto (interview at Bandung, 27th April 2017)
   Professional description:

   - Research advisor at the Centre for Research on Energy Policy at ITB
   - Associate Professor at Petroleum Engineering Department of ITB

3. Dr Muhammad Tasrif (interview at Bandung, 26th April 2017)
   Professional description:

   - Expert in systems dynamics modeling and in Indonesian policy analysis.
   - Head of Master Programme in Development Studies at ITB

APPENDIX G: MODEL USEFULNESS TEST

Procedures from identification up to completing data and information collection:

Each of the participants was sent an invitation letter and an information sheet about the research and their participation. After accepting the invitation, the participants were sent the interview guideline and questionnaire. The interview meeting started with a presentation about the research and the modelling results, then the participant filled in the questionnaire. The participants can ask any questions about the research and their participation since before the meeting was held.

List of participants:

1. The Ministry of Energy and Mineral Resources
    a. Director of Bioenergy (Jakarta, 9th May 2017)
    b. Secretary for Directorate General of New Renewable Energy and Energy Conservation; Former Director of Bioenergy (Jakarta, 4th May 2017)
2. The Ministry of Environment and Forestry
   Head for Legal Affairs and Technical Cooperation in Management of Watershed and Protected Forest (Jakarta, 9th May 2017)
3. The Ministry of Research, Technology, and Higher Education
   Director for Research and Development System (Jakarta, 11th May 2017)
4. The Ministry of Industry
   Head for Industry Empowerment of Non-food Plantations (Jakarta, 10th May 2017)

QUESTIONNAIRE

MODEL USEFULNESS

1. **Relevance**
   Is this model relevant with the contribution to a better understanding in a policy formulation and planning for sustainable bioenergy in Indonesia that considers marginal land use and appropriate technology readiness?

1 = Low relevance	2 = Medium relevance	3 = High relevance

   Reasons: ……………………………………………………

2. **Reliability**
   Is this model reliable for policy formulation and planning for sustainable bioenergy in Indonesia that considers marginal land use and appropriate technology readiness?

1 = Low reliability	2 = Medium reliability	3 = High reliability

   Reasons: …………………………………………….

3. **Practicality**
   Is this model practical for policy formulation and planning for sustainable bioenergy in Indonesia that considers marginal land use and appropriate technology readiness?

1 = Low practicality	2 = Medium practicality	3 = High practicality

   Reasons: ……………………………………………………

4. **Importance**
   Is this model important for policy formulation and planning for sustainable bioenergy in Indonesia that considers marginal land use and appropriate technology readiness?

1 = Low importance	2 = Medium importance	3 = High importance

   Reasons: ……………………………………………………

5. Suggestion/comments: ……….

APPENDIX H : PERSONAL COMMUNICATIONS

The communications were conducted either intentionally or incidentally. Time and place when inputs were provided, are stated in the references.

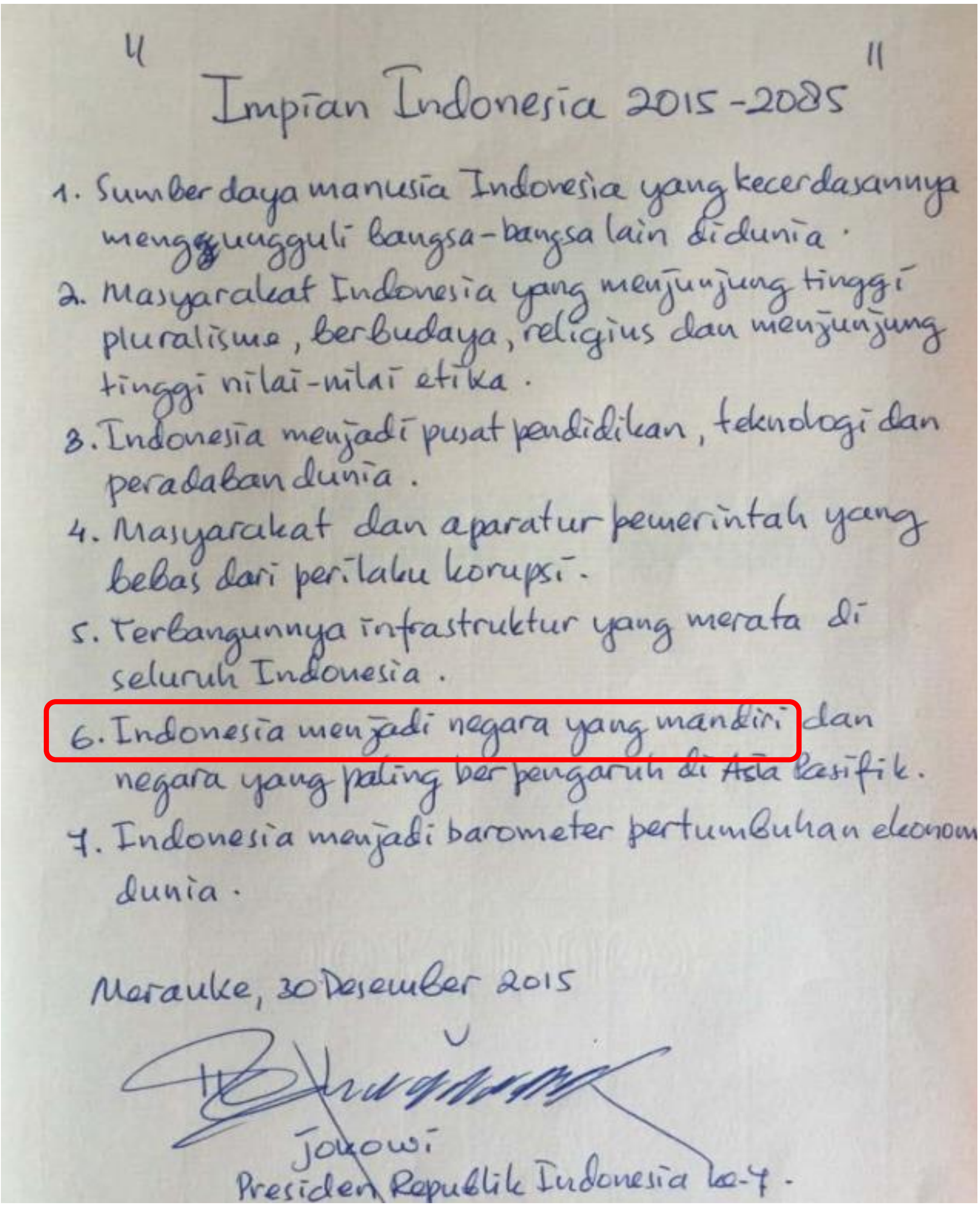
List of persons whose inputs were cited in this thesis:

1. Dr Tatang H. Soerawidjaja
    - President of the Indonesian Association of Bioenergy Scientists and Technologists.
    - Initiator and group leader for DBF technology development via metal soap decarboxylation at Institute of Technology of Bandung (ITB).
    - Former Chairman of the Center for Research on Energy and Material at ITB
    - Associate Professor at Chemical Engineering Department of ITB.
2. Dr Muhammad Tasrif
    - Expert in systems dynamics and Indonesian policy analysis.
    - Head of master programme in Development Studies of ITB
3. Prof Dr Subagjo
    - The most senior in the research of hydrodeoxygenation technology for DBF production.
    - Professor in chemical reaction engineering and catalysis at ITB.
4. Prof Dr Fahmuddin Agus
    - Expert in soil science, land use and GHG mitigation issues
    - Researcher at the Indonesian Soil Research Institute

APPENDIX I : THE INDONESIAN DREAM 2015-2085

"The Indonesian Dream 2015-2085 *(Impian Indonesia 2015-2085)*"

(Mr Joko Widodo (Jokowi) the 7th President, 2015)



"Impian Indonesia 2015-2085"

1. Sumber daya manusia Indonesia yang kecerdasannya mengungguli bangsa-bangsa lain di dunia.
2. Masyarakat Indonesia yang menjunjung tinggi pluralisme, berbudaya, religius dan menjunjung tinggi nilai-nilai etika.
3. Indonesia menjadi pusat pendidikan, teknologi dan peradaban dunia.
4. Masyarakat dan aparatur pemerintah yang bebas dari perilaku korupsi.
5. Terbangunnya infrastruktur yang merata di seluruh Indonesia.
6. Indonesia menjadi negara yang mandiri dan negara yang paling berpengaruh di Asia Pasifik.
7. Indonesia menjadi barometer pertumbuhan ekonom dunia.

Merauke, 30 Desember 2015

Jokowi
Presiden Republik Indonesia ke-7.

Translation for the marked words: "6. Indonesia to become an independent country"

APPENDIX J : ABMIC MODEL EQUATIONS

Accumulated_TR_investment(t) = Accumulated_TR_investment(t - dt) + (TR_investment_flow) * dt

INIT Accumulated_TR_investment = 0

UNITS: %

INFLOWS:

TR_investment_flow = IF TR_Investment_balance>=0 THEN 0 ELSE TR_Investment_balance*-1*Supports_on_technology_readiness/Investment_time

UNITS: %/Years

Actual_year_of_planting_start = IF Sumba_developed_marginal_land_area > Land_area_for_a_DBF_plant AND PREVIOUS(SELF, -1) < 0 THEN TIME ELSE PREVIOUS(SELF, -1)

UNITS: year

Added_biodiesel_capacity = MAX(0, (Desired_biodiesel_capacity/Time_to_adjust_biodiesel_capacity-Remaining_biodiesel_capacity))

UNITS: kL/yr/yr

Approach_to_farmers_by_ethnic_elders_or_association = 1

UNITS: dimensionless

Average_oilseeds_yield = ("Oilseeds_yield*_4"+"Oilseeds_yield*_5"+"Oilseeds_yield*_6"+"Oilseeds_yield*_7"+"Oilseeds_yield*_8"+"Oilseeds_yield*_9"+"Oilseeds_yield*_10"+"Oilseeds_yield*_11"+"Oilseeds_yield*_12"+"Oilseeds_yield*_13"+"Oilseeds_yield*_14"+"Oilseeds_yield*_15")*Trees_per_Ha*Block_harvested/(Total_blocks_planted-"Number_of_non-oilseeds_harvest_blocks")

UNITS: ton/ha

Averaging_consumption_time = 1

UNITS: year

Avoided_CO2_emission_from_DBF_consumption = Sumba_DBF_consumption*Fossil_fuel_CO2_emission_factor

UNITS: ton CO2e/yr

Avoided_CO2_emission_from_diesel_electricity = Equiv_diesel_consumption_for_electricity*Diesel_electricity_CO2_emission_factor

UNITS: ton CO2e/yr

"Balance_of_Trade_(BOT)" = National_Export_value-National_Import_value

UNITS: US $/yr

"bbl/kl" = 1000/159

UNITS: bbl/kL

Biodiesel_capacity_life_time = 20

UNITS: year

Biodiesel_capacity_under_construction(t) = Biodiesel_capacity_under_construction(t - dt) + (Starting_biodiesel_construction - Completing_biodiesel_construction) * dt

INIT Biodiesel_capacity_under_construction = 0

UNITS: kL/yr

INFLOWS:

Starting_biodiesel_construction = Added_biodiesel_capacity

UNITS: kl/yr/yr

OUTFLOWS:

Completing_biodiesel_construction = Biodiesel_capacity_under_construction/Biodiesel_plant_construction_time

UNITS: kl/yr/yr

Biodiesel_converting_cost = 100

UNITS: US $/ton

Biodiesel_existing_mandate = GRAPH(TIME)

(2018.00, 6700000), (2019.00, 6700000), (2020.00, 10700000), (2021.00, 11500000), (2022.00, 12300000), (2023.00, 13100000), (2024.00, 13800000), (2025.00, 14600000), (2026.00, 15400000), (2027.00, 16200000), (2028.00, 17000000), (2029.00, 17800000), (2030.00, 18600000), (2031.00, 19400000), (2032.00, 20100000), (2033.00, 21300000), (2034.00, 22400000), (2035.00, 23500000), (2036.00, 24700000), (2037.00, 25800000), (2038.00, 26900000), (2039.00, 28100000), (2040.00, 29500000), (2041.00, 30600000), (2042.00, 31700000), (2043.00, 32800000), (2044.00, 33800000), (2045.00, 34900000)

UNITS: kl/yr

Biodiesel_export_quota = 1e6

UNITS: kL/yr

Biodiesel_plant_construction_time = 2

UNITS: year

Biodiesel_price = (CPO_price+Biodiesel_converting_cost)/"kL/ton_palm_oil"

UNITS: US $/kL

Biodiesel_production = Biodiesel_production_capacity

UNITS: kl/yr

Biodiesel_production_capacity(t) = Biodiesel_production_capacity(t - dt) + (Completing_biodiesel_construction - Discarding_biodiesel_capacity) * dt

INIT Biodiesel_production_capacity = 6.5e6

UNITS: kL/yr

INFLOWS:

Completing_biodiesel_construction = Biodiesel_capacity_under_construction/Biodiesel_plant_construction_time

UNITS: kl/yr/yr

OUTFLOWS:

Discarding_biodiesel_capacity = Biodiesel_production_capacity/Biodiesel_capacity_life_time

UNITS: kl/yr/yr

Biodiesel_Stock(t) = Biodiesel_Stock(t - dt) + (Biodiesel_supply - Biodiesel_consumption) * dt

INIT Biodiesel_Stock = 0

UNITS: kL

INFLOWS:

Biodiesel_supply = Biodiesel_production-Biodiesel_export_quota

UNITS: kl/yr

OUTFLOWS:

Biodiesel_consumption = IF Liquid_biofuel_share_target>1e-8 THEN Biodiesel_Stock/Time_averaging_biodiesel_consumption ELSE 0

UNITS: kl/yr

Block_harvested = 1

UNITS: block

"By-products_revenues" = 1000

UNITS: IDR/L

C_stock_open_land = 2.5

UNITS: ton CO2e/ha

Carbon_stock_per_tree = 250*1e-3

UNITS: ton C / tree

CO2_emission_from_DBF_production = Sumba_DBF_production*DBF_CO2_emission_factor

UNITS: ton CO2e/yr

CO2_emission_from_marginal_land_carbon_stock = "CO2_emission_from_marginal_land_carbon_stock_pre-peak"+CO2_emission_from_marginal_land_carbon_stock_peak

UNITS: ton CO2e/Years

CO2_emission_from_marginal_land_carbon_stock_peak = IF TIME >=Actual_year_of_planting_start+Crop_rotation_cycle AND Actual_year_of_planting_start>0 AND

"CO2_emission_from_marginal_land_carbon_stock_pre-peak"=0 THEN ((C_stock_open_land-CO2e_sequestrated_per_tree*Trees_per_Ha)*INIT (Marginal_land_area_available_for_energy_crop)/Crop_rotation_cycle) ELSE 0

UNITS: ton CO2e/Years

"CO2_emission_from_marginal_land_carbon_stock_pre-peak" = IF TIME <=Actual_year_of_planting_start+Crop_rotation_cycle AND Actual_year_of_planting_start>0 THEN ((C_stock_open_land-CO2e_sequestrated_per_tree*Trees_per_Ha)*INIT (Marginal_land_area_available_for_energy_crop)/Crop_rotation_cycle)*(TIME-Actual_year_of_planting_start)/Crop_rotation_cycle ELSE 0

UNITS: ton CO2e/Years

CO2e_sequestrated_per_tree = Carbon_stock_per_tree*"Ton_CO2e_/_ton_C"

UNITS: ton CO2e / tree

Concentration_of_diesel_combustion_booster = 0.2

UNITS: dimensionless

CPO_average_productivity(t) = CPO_average_productivity(t - dt) + (CPO_productivity_increase_rate) * dt

INIT CPO_average_productivity = 3

UNITS: ton/ha

INFLOWS:

CPO_productivity_increase_rate = CPO_productivity_increase_target/Expected_time_to_increase_CPO_productivity

UNITS: ton/Ha/yr

CPO_price = GRAPH(TIME)

(2018.00, 490), (2019.00, 500), (2020.00, 500), (2021.00, 510), (2022.00, 510), (2023.00, 520), (2024.00, 520), (2025.00, 530), (2026.00, 550), (2027.00, 560), (2028.00, 560), (2029.00, 560), (2030.00, 560), (2031.00, 560), (2032.00, 560), (2033.00, 570), (2034.00, 580), (2035.00, 590), (2036.00, 590), (2037.00, 600), (2038.00, 610), (2039.00, 620), (2040.00, 620), (2041.00, 620), (2042.00, 620), (2043.00, 620), (2044.00, 640), (2045.00, 640)

UNITS: US $/ton

CPO_productivity_increase_target = CPO_productivity_target-CPO_average_productivity

UNITS: ton/ha

CPO_productivity_target = 5

UNITS: ton/ha

Crop_rotation_cycle = 10

UNITS: year

Crude_oil_export_volume = GRAPH(TIME)

(2018.00, 80000000), (2019.00, 76000000), (2020.00, 72000000), (2021.00, 68000000), (2022.00, 64000000), (2023.00, 60000000), (2024.00, 56000000), (2025.00, 52000000), (2026.00, 48000000), (2027.00, 43000000), (2028.00, 39000000), (2029.00, 35000000), (2030.00, 31000000), (2031.00, 27000000), (2032.00, 23000000), (2033.00, 19000000), (2034.00, 15000000), (2035.00, 5000000), (2036.00, 0), (2037.00, 0), (2038.00, 0), (2039.00, 0), (2040.00, 0), (2041.00, 0), (2042.00, 0), (2043.00, 0), (2044.00, 0), (2045.00, 0)

UNITS: bbl/yr

Crude_oil_import_volume = GRAPH(TIME)

(2018.00, 175000000), (2019.00, 1.9e+08), (2020.00, 2e+08), (2021.00, 2.2e+08), (2022.00, 2.5e+08), (2023.00, 3.5e+08), (2024.00, 4e+08), (2025.00, 5e+08), (2026.00, 5e+08), (2027.00, 5e+08), (2028.00, 5e+08), (2029.00, 5.8e+08), (2030.00, 6.4e+08), (2031.00, 6.4e+08), (2032.00, 6.4e+08), (2033.00, 6.4e+08), (2034.00, 6.4e+08), (2035.00, 7e+08), (2036.00, 7.5e+08), (2037.00, 7.5e+08), (2038.00, 7.5e+08), (2039.00, 8e+08), (2040.00, 8.5e+08), (2041.00, 8.5e+08), (2042.00, 8.5e+08), (2043.00, 8.5e+08), (2044.00, 8.5e+08), (2045.00, 9.5e+08)

UNITS: bbl/yr

DBF_capacity_life_time = 20

UNITS: year

DBF_CO2_emission_factor = 0.5

UNITS: ton CO2e/kL

DBF_converting_cost = 0.36

UNITS: US $/L

DBF_export_quota = 1e6

UNITS: kL/yr

DBF_fraction_for_diesel = 0.4

UNITS: dimensionless

DBF_plant_construction_time = 2

UNITS: year

DBF_price = "DBF_price_IDR/kL"/"IDR/USD"*"L/kL"

UNITS: US $/kL

"DBF_price_IDR/kL" = IF National_DBF_production > 0 THEN (Pongamia_DBF_production_cost*National_DBF_production_from_marginal_lland +DBF_production_from_palm_oil*Palm_DBF_production_cost)/(National_DBF_production_from_marginal_lland+DBF_production_from_palm_oil)*(1+DBF_profit_margin) ELSE 0

UNITS: IDR/L

DBF_production_from_palm_oil = IF Sumba_DBF_production_capacity>0 AND Palm_oil_consumption_for_biodiesel_&_DBF>Palm_oil_demand_for_biodiesel THEN

(Palm_oil_available_for_DBF+(Palm_oil_consumption_for_biodiesel_&_DBF-Palm_oil_demand_for_biodiesel))*"kL/ton_palm_oil" ELSE 0

UNITS: kL/yr

DBF_production_time = 1

UNITS: year

DBF_profit_margin = 0.1

UNITS: dimensionless

DBF_stock_sufficiency_period = 1/12

UNITS: year

Desired_biodiesel_capacity = IF National_DBF_production<=0 THEN Biodiesel_existing_mandate ELSE Concentration_of_diesel_combustion_booster*National_production_of_diesel_type_DBF

UNITS: kL/yr

Desired_DBF_production_per_plant = 50000

UNITS: kL/yr

Desired_TR = 1

UNITS: dimensionless

Desired_year_of_Pongamia_oil_feedstock_ready = Year_of_technology_commercially_ready

UNITS: year

Diesel_electricity_CO2_emission_factor = 2.9

UNITS: ton CO2e/kL

DMO_palm_oil = 0.9

UNITS: dimensionless

Equiv_diesel_consumption_for_electricity = Sumba_woodfuel_for_harvest/Averaging_consumption_time*Woodfuel_calor*"kL_diesel_/_MWh"

UNITS: kl/yr

"Expected_time_of_post-technical_readiness" = 3

UNITS: yr

Expected_time_to_develop_land = 3

UNITS: year

Expected_time_to_increase_CPO_productivity = 2045-2018

UNITS: year

Expected_time_to_progress_TR = 5

UNITS: yr

Foreign_exchange_saving = National_DBF_consumption*DBF_price+Biodiesel_consumption*Biodiesel_price

UNITS: US $ / yr

Fossil_fuel_CO2_emission_factor = 2.8

UNITS: ton CO2e/kL

Fraction_of_government_support = 0.5

UNITS: dimensionless

Fraction_palm_oil_consumption_for_food_&_oleo_excluding_biodiesel = 0.1

UNITS: dimensionless

"Fuel_price_difference_(FPD)" = IF National_DBF_production<=0 THEN (Oil_fuels_price-Biodiesel_price) ELSE (Oil_fuels_price-DBF_price)

UNITS: US $/kL

Future_vision_power = 1

UNITS: dimensionless

Gas_export_volume = GRAPH(TIME)

(2018.00, 900), (2019.00, 800), (2020.00, 750), (2021.00, 600), (2022.00, 600), (2023.00, 400), (2024.00, 300), (2025.00, 300), (2026.00, 250), (2027.00, 225), (2028.00, 200), (2029.00, 175), (2030.00, 150), (2031.00, 125), (2032.00, 100), (2033.00, 75), (2034.00, 50), (2035.00, 25), (2036.00, 0), (2037.00, 0), (2038.00, 0), (2039.00, 0), (2040.00, 0), (2041.00, 0), (2042.00, 0), (2043.00, 0), (2044.00, 0), (2045.00, 0)

UNITS: BCF/yr

Gas_import_volume = GRAPH(TIME)

(2018.00, 0), (2019.00, 0), (2020.00, 0), (2021.00, 0), (2022.00, 0), (2023.00, 0), (2024.00, 25), (2025.00, 50), (2026.00, 100), (2027.00, 200), (2028.00, 300), (2029.00, 500), (2030.00, 700), (2031.00, 800), (2032.00, 900), (2033.00, 900), (2034.00, 1000), (2035.00, 1100), (2036.00, 1300), (2037.00, 1700), (2038.00, 1900), (2039.00, 2000), (2040.00, 2200), (2041.00, 2300), (2042.00, 2350), (2043.00, 3000), (2044.00, 3500), (2045.00, 3800)

UNITS: BCF/yr

Gas_price = GRAPH(TIME)

(2018.00, 8.80), (2019.00, 8.90), (2020.00, 9.10), (2021.00, 9.30), (2022.00, 9.40), (2023.00, 9.60), (2024.00, 9.70), (2025.00, 9.90), (2026.00, 9.90), (2027.00, 9.90), (2028.00, 10.00), (2029.00, 10.00), (2030.00, 10.00), (2031.00, 9.90), (2032.00, 9.80), (2033.00, 9.70), (2034.00, 9.70), (2035.00, 9.60), (2036.00, 9.50), (2037.00, 9.40), (2038.00, 9.30), (2039.00, 9.20), (2040.00, 9.10), (2041.00, 9.00), (2042.00, 9.00), (2043.00, 8.90), (2044.00, 8.80), (2045.00, 8.70)

UNITS: US $/MMBtu

Government_support_for_income_guarantee = Sense_of_urgency_by_the_President

UNITS: dimensionless

Government_support_for_infrastructure = Sense_of_urgency_by_the_President

UNITS: dimensionless

Government_support_for_landowners'_understanding = Sense_of_urgency_by_the_President

UNITS: dimensionless

"Government_support_for_Sumba_Iconic_Island_(SII)_program" = Sense_of_urgency_by_the_President

UNITS: dimensionless

Government_support_for_the_Regent's_commitment = Sense_of_urgency_by_the_President

UNITS: dimensionless

Growth_year_1 = 0.5e-3

UNITS: ton/tree

Growth_year_10 = IF Crop_rotation_cycle<10 THEN 0 ELSE (0)*1e-3

UNITS: ton/tree

Growth_year_11 = IF Crop_rotation_cycle<11 THEN 0 ELSE (0)*1e-3

UNITS: ton/tree

Growth_year_12 = IF Crop_rotation_cycle<12 THEN 0 ELSE (0)*1e-3

UNITS: ton/tree

Growth_year_13 = IF Crop_rotation_cycle<13 THEN 0 ELSE (0)*1e-3

UNITS: ton/tree

Growth_year_14 = IF Crop_rotation_cycle<14 THEN 0 ELSE (0)*1e-3

UNITS: ton/tree

Growth_year_15 = IF Crop_rotation_cycle<15 THEN 0 ELSE (0)*1e-3

UNITS: ton/tree

Growth_year_2 = (3-0.5)*1e-3

UNITS: ton/tree

Growth_year_3 = (20-3)*1e-3

UNITS: ton/tree

Growth_year_4 = (90-65)*1e-3

UNITS: ton/tree

Growth_year_5 = (120-90)*1e-3

UNITS: ton/tree

Growth_year_6 = IF Crop_rotation_cycle<6 THEN 0 ELSE (140-120)*1e-3

UNITS: ton/tree

Growth_year_7 = IF Crop_rotation_cycle<7 THEN 0 ELSE (185-140)*1e-3

UNITS: ton/tree

Growth_year_8 = IF Crop_rotation_cycle<8 THEN 0 ELSE (210-185)*1e-3

UNITS: ton/tree

Growth_year_9 = IF Crop_rotation_cycle<9 THEN 0 ELSE (0)*1e-3

UNITS: ton/tree

"harvesting_time/block" = 1

UNITS: yr/block

"IDR/USD" = 15000

UNITS: IDR/US $

Income_guarantee = Government_support_for_income_guarantee

UNITS: dimensionless

Infrastructure_readiness = DELAY1((Government_support_for_infrastructure*Fraction_of_government_support+NGO_support*(1-Fraction_of_government_support)*Local_government_commitment*Land_status_clarity), Time_to_progress_infrastructure, IV_infrastructure_readiness)

UNITS: dimensionless

Investment_interval = 5

UNITS: dimensionless

Investment_required_for_TR = 100

UNITS: %

Investment_time = ((Expected_time_to_progress_TR)/Investment_interval)

UNITS: yr

IV_infrastructure_readiness = 0.2

UNITS: dimensionless

IV_land_certification = 0.2

UNITS: dimensionless

IV_landowners'_respect = 1

UNITS: dimensionless

IV_landowners'_understanding = 0.5

UNITS: dimensionless

IV_local_government_commitment = 0.6

UNITS: dimensionless

"kL_biodiesel/_ton_palm_oil" = 1.1

UNITS: kL/ton

"kL_diesel_/_MWh" = 0.28

UNITS: kl/MWh

"kL/ton_palm_oil" = 1.1

UNITS: kL/ton

"kL/ton_Pongamia_oil" = 1.1

UNITS: kL/ton

"L/kL" = 1000

UNITS: L/kL

Land_area_for_a_DBF_plant = Required_oilseeds_per_DBF_plant/Average_oilseeds_yield*Total_blocks_planted/(Total_blocks_planted-"Number_of_non-oilseeds_harvest_blocks")

UNITS: ha

Land_certification_by_BPN = DELAY1(Landowners'_willingness_to_cultivate*Local_government_commitment, Time_to_increase_land_certification, IV_land_certification)

UNITS: dimensionless

Land_status_clarity = (Land_tenure+Land_certification_by_BPN)/2

UNITS: dimensionless

Land_tenure = Landowners'_willingness_to_cultivate

UNITS: dimensionless

Landowners'_respect_to_government = DELAY1(Landowners'_understanding, 1, IV_landowners'_respect)

UNITS: dimensionless

Landowners'_understanding = DELAY1((Government_support_for_landowners'_understanding+Approach_to_farmers_by_ethnic_elders_or_association+NGO_support)/3*Local_government_commitment, Time_for_private_landowners'_to_understand, IV_landowners'_understanding)

UNITS: dimensionless

Landowners'_willingness_to_cultivate = (Landowners'_understanding+Income_guarantee+Landowners'_respect_to_government+Infrastructure_readiness)/4

UNITS: Dimensionless

Learning_effect_of_DBF_production = IF National_DBF_production>0 THEN 1 ELSE 0

UNITS: dimensionless

Learning_effect_of_Pongamia_oil_feedstock_production = IF Sumba_oil_feedstock_for_DBF_production>0 THEN 1 ELSE 0

UNITS: dmnl

Liquid_biofuel_consumption_value = Biodiesel_consumption*Biodiesel_price+National_DBF_consumption*DBF_price

UNITS: US $ / yr

Liquid_biofuel_export_value = Biodiesel_export_quota*Biodiesel_price+DBF_export_quota*DBF_price

UNITS: US $ / yr

Liquid_biofuel_share_target = IF Price_ratio_of_biofuel_to_oil_fuel<=1 THEN 1 ELSE Sense_of_urgency_by_the_President

UNITS: dimensionless

Local_government_commitment = DELAY1((Local_government_interest_on_SII_program+The_Regent's_commitment_strength_for_energy_crop)/2, Time_to_change_local_government_commitment, IV_local_government_commitment)

UNITS: dimensionless

Local_government_interest_on_SII_program = "Government_support_for_Sumba_Iconic_Island_(SII)_program"

UNITS: dimensionless

LPG_import_demand_volume = GRAPH(TIME)

(2018.00, 4.6), (2019.00, 4.9), (2020.00, 5.2), (2021.00, 5.2), (2022.00, 5.2), (2023.00, 5.5), (2024.00, 5.8), (2025.00, 5.4), (2026.00, 5), (2027.00, 5.5), (2028.00, 6), (2029.00, 6.4), (2030.00, 6.8), (2031.00, 6.9), (2032.00, 7), (2033.00, 7.3), (2034.00, 7.6), (2035.00, 7.6), (2036.00, 7.6), (2037.00, 8.1), (2038.00, 8.6), (2039.00, 8.8), (2040.00, 9), (2041.00, 9.3), (2042.00, 9.6), (2043.00, 10.1), (2044.00, 10.5), (2045.00, 10.5)

UNITS: Mt/yr

LPG_price = Oil_price/"Mt/bbl"

UNITS: US $/Mt

Marginal_land_area_available_for_energy_crop(t) = Marginal_land_area_available_for_energy_crop(t - dt) + (- Marginal_lland_development_rate) * dt

INIT Marginal_land_area_available_for_energy_crop = 200000

UNITS: ha

OUTFLOWS:

Marginal_lland_development_rate = IF TIME<STARTTIME+Time_to_develop_land THEN 0 ELSE MAX(0, Marginal_land_area_available_for_energy_crop)/Time_to_develop_land

UNITS: Hectares/Years

Marginal_land_feedstock_management = 1

UNITS: dimensionless

"MMBtu_/BCF" = 1.01e6

UNITS: MMBtu/BCF

"Mt/bbl" = 0.086/1000

UNITS: Mt/bbl

National_accumulated_CO2_emission = National_to_Sumba_marginal_land_area_multiplier*Sumba_accumulated_CO2_emissions

UNITS: ton CO2e

National_CO2_emissions = Sumba_CO2_emissions*National_to_Sumba_marginal_land_area_multiplier

UNITS: ton CO2e/yr

National_DBF_consumption = MAX(0, National_liquid_biofuel_consumption-Biodiesel_consumption)

UNITS: kL/yr

National_DBF_production = National_DBF_production_from_marginal_lland+DBF_production_from_palm_oil

UNITS: kL/yr

National_DBF_production_from_marginal_lland = Sumba_DBF_production*National_to_Sumba_marginal_land_area_multiplier

UNITS: kL/yr

National_Export_value = Oil_&_gas_export_value+ Non_oil_&_gas_export_value+Liquid_biofuel_export_value

UNITS: US $/yr

National_Import_value = Oil_&_gas_import_value+Non_oil_&_gas_import_value

UNITS: US $/yr

National_liquid_biofuel_consumption = MIN(National_liquid_biofuel_for_consumption, Liquid_biofuel_share_target*National_liquid_fuel_demand)

UNITS: kl/yr

National_liquid_biofuel_desired_stock = National_liquid_biofuel_stock_sufficiency_period*National_liquid_biofuel_for_consumption

UNITS: kL

National_liquid_biofuel_for_export = IF National_liquid_fuel_import_demand=0 THEN MIN (National_oil_fuels_production+National_liquid_biofuel_production-National_liquid_fuel_demand, National_liquid_biofuel_surplus+Biodiesel_export_quota+DBF_export_quota) ELSE 0

UNITS: kL/yr

National_liquid_biofuel_production = Biodiesel_production+National_DBF_production

UNITS: kl/yr

National_liquid_biofuel_stock(t) = National_liquid_biofuel_stock(t - dt) + (National_liquid_biofuel_supply - National_liquid_biofuel_for_consumption) * dt

INIT National_liquid_biofuel_stock = 0

UNITS: kL

INFLOWS:

National_liquid_biofuel_supply = National_liquid_biofuel_production-National_liquid_biofuel_for_export

UNITS: kl/yr

OUTFLOWS:

National_liquid_biofuel_for_consumption = IF National_liquid_biofuel_production>=National_liquid_fuel_demand THEN National_liquid_fuel_demand ELSE National_liquid_biofuel_stock/Time_to_average_national_liquid_biofuel_for_consumption

UNITS: kL/yr

National_liquid_biofuel_stock_sufficiency_period = 1/12

UNITS: year

National_liquid_biofuel_surplus = IF National_liquid_biofuel_stock>National_liquid_biofuel_desired_stock THEN ((National_liquid_biofuel_stock-National_liquid_biofuel_desired_stock)/Time_averaging_national_liquid_biofuel_surplus) ELSE 0

UNITS: kl/yr

National_liquid_fuel_demand = GRAPH(TIME)

(2018.00, 7.5e+07), (2019.00, 7.5e+07), (2020.00, 8e+07), (2021.00, 8.6e+07), (2022.00, 9.2e+07), (2023.00, 9.7e+07), (2024.00, 1.03e+08), (2025.00, 1.09e+08), (2026.00, 1.15e+08), (2027.00, 1.21e+08), (2028.00, 1.27e+08), (2029.00, 1.33e+08), (2030.00, 1.38e+08), (2031.00, 1.44e+08), (2032.00, 1.5e+08), (2033.00, 1.58e+08), (2034.00, 1.67e+08), (2035.00, 1.75e+08), (2036.00, 1.84e+08), (2037.00, 1.92e+08), (2038.00, 2.01e+08), (2039.00, 2.09e+08), (2040.00, 2.2e+08), (2041.00, 2.28e+08), (2042.00, 2.36e+08), (2043.00, 2.44e+08), (2044.00, 2.52e+08), (2045.00, 2.6e+08)

UNITS: kL/yr

National_liquid_fuel_import_demand = IF National_oil_fuels_production+National_liquid_biofuel_production>=National_liquid_fuel_demand THEN 0 ELSE National_liquid_fuel_demand-(National_oil_fuels_production+National_liquid_biofuel_production)

UNITS: kL/yr

"National_liquid_fuel_self-sufficiency" = (National_liquid_fuel_demand-National_liquid_fuel_import_demand)/National_liquid_fuel_demand

UNITS: dimensionless

National_lliquid_biofuel_actual_share = National_liquid_biofuel_consumption/National_liquid_fuel_demand

UNITS: dimensionless

National_oil_fuels_production = GRAPH(TIME)

(2018.00, 4.5e+07), (2019.00, 4.5e+07), (2020.00, 4.5e+07), (2021.00, 5e+07), (2022.00, 5e+07), (2023.00, 5.5e+07), (2024.00, 6e+07), (2025.00, 6.5e+07), (2026.00, 8e+07), (2027.00, 8.5e+07), (2028.00, 9e+07), (2029.00, 9.5e+07), (2030.00, 1e+08), (2031.00, 1e+08), (2032.00, 1e+08), (2033.00, 1.05e+08), (2034.00, 1.05e+08), (2035.00, 1.1e+08), (2036.00, 1.1e+08), (2037.00, 1.15e+08), (2038.00, 1.2e+08), (2039.00, 1.2e+08), (2040.00, 1.25e+08), (2041.00, 1.25e+08), (2042.00, 1.25e+08), (2043.00, 1.3e+08), (2044.00, 1.3e+08), (2045.00, 1.35e+08)

UNITS: kL/yr

National_production_of_diesel_type_DBF = DBF_fraction_for_diesel*National_DBF_production

UNITS: kl/yr

National_to_Sumba_marginal_land_area_multiplier = 50

UNITS: dimensionless

Net_CO2_emission_from_bioelectricity = Woodfuel_CO2_emission_from_bioelectricity-Avoided_CO2_emission_from_diesel_electricity

UNITS: ton CO2e/yr

Net_CO2_emission_from_DBF = CO2_emission_from_DBF_production-Avoided_CO2_emission_from_DBF_consumption

UNITS: ton CO2e/yr

NGO_support = 1

UNITS: dimensionless

Non_oil_&_gas_export_value = GRAPH(TIME)

(2018.00, 160738000000), (2019.00, 168775000000), (2020.00, 177214000000), (2021.00, 186074000000), (2022.00, 195378000000), (2023.00, 205147000000), (2024.00, 215404000000), (2025.00, 226174000000), (2026.00, 237483000000), (2027.00, 249357000000), (2028.00, 261825000000), (2029.00, 274917000000), (2030.00, 288662000000), (2031.00, 303095000000), (2032.00, 318250000000), (2033.00, 334163000000), (2034.00, 350871000000), (2035.00, 368414000000), (2036.00, 386835000000), (2037.00, 406177000000), (2038.00, 426486000000), (2039.00, 447810000000), (2040.00, 470201000000), (2041.00, 493711000000), (2042.00, 518396000000), (2043.00, 544316000000), (2044.00, 571532000000), (2045.00, 600108000000)

UNITS: US $/yr

Non_oil_&_gas_import_value = GRAPH(TIME)

(2018.00, 139303000000), (2019.00, 146268000000), (2020.00, 153581000000), (2021.00, 161260000000), (2022.00, 169323000000), (2023.00, 177790000000), (2024.00, 186679000000), (2025.00, 196013000000), (2026.00, 205814000000), (2027.00, 216104000000), (2028.00, 226910000000), (2029.00, 238255000000), (2030.00, 250168000000), (2031.00, 262676000000), (2032.00, 275810000000), (2033.00, 289600000000), (2034.00, 304080000000), (2035.00, 319284000000), (2036.00, 335249000000), (2037.00, 352011000000), (2038.00, 369612000000), (2039.00, 388092000000), (2040.00, 407497000000), (2041.00, 427872000000), (2042.00, 449265000000), (2043.00, 471729000000), (2044.00, 495315000000), (2045.00, 520081000000)

UNITS: US $/yr

"Number_of_non-oilseeds_harvest_blocks" = Time_length_from_cultivation_to_first_harvest/"harvesting_time/block"

UNITS: block

Oil_&_gas_export_value = Crude_oil_export_volume*Oil_price+Gas_export_volume*"MMBtu_/BCF"*Gas_price

UNITS: US $/yr

Oil_&_gas_import_value = Crude_oil_import_volume*Oil_price+LPG_import_demand_volume*LPG_price*1000+National_liquid_fuel_import_demand*Oil_products_price+Gas_import_volume*"MMBtu_/BCF"*Gas_price-Liquid_biofuel_consumption_value

UNITS: US $/yr

Oil_content_in_seeds = 0.4

UNITS: dimensionless

Oil_feedstock_conversion = 0.76

UNITS: dimensionless

Oil_fuels_price = Oil_products_price

UNITS: US $/kL

Oil_palm_plantation_area = 14e6

UNITS: ha

Oil_price = GRAPH(TIME)

(2018.00, 65.0), (2019.00, 66.7), (2020.00, 66.4), (2021.00, 67.1), (2022.00, 67.9), (2023.00, 68.6), (2024.00, 69.3), (2025.00, 70.0), (2026.00, 70.0), (2027.00, 70.0), (2028.00, 70.0), (2029.00, 70.0), (2030.00, 70.0), (2031.00, 69.0), (2032.00, 68.0), (2033.00, 67.0), (2034.00, 66.0), (2035.00, 65.0), (2036.00, 65.0), (2037.00, 65.0), (2038.00, 65.0), (2039.00, 65.0), (2040.00, 65.0), (2041.00, 65.0), (2042.00, 65.0), (2043.00, 65.0), (2044.00, 65.0), (2045.00, 65.0)

UNITS: US $/bbl

Oil_products_price = Oil_price*"bbl/kl"*1.5

UNITS: US $/kL

Oilseeds_price = 15

UNITS: US $/ton

Oilseeds_yield_10 = 0.025

UNITS: ton/tree

Oilseeds_yield_11 = 0.025

UNITS: ton/tree

Oilseeds_yield_12 = 0.025

UNITS: ton/tree

Oilseeds_yield_13 = 0.025

UNITS: ton/tree

Oilseeds_yield_14 = 0.025

UNITS: ton/tree

Oilseeds_yield_15 = 0.025

UNITS: ton/tree

Oilseeds_yield_4 = 0.01

UNITS: ton/tree

Oilseeds_yield_5 = 0.01

UNITS: ton/tree

Oilseeds_yield_6 = 0.013

UNITS: ton/tree

Oilseeds_yield_7 = 0.014

UNITS: ton/tree

Oilseeds_yield_8 = 0.025

UNITS: ton/tree

Oilseeds_yield_9 = 0.025

UNITS: ton/tree

"Oilseeds_yield*_10" = IF Crop_rotation_cycle<10 THEN 0 ELSE Oilseeds_yield_10

UNITS: ton/tree

"Oilseeds_yield*_11" = IF Crop_rotation_cycle<11 THEN 0 ELSE Oilseeds_yield_11

UNITS: ton/tree

"Oilseeds_yield*_12" = IF Crop_rotation_cycle<12 THEN 0 ELSE Oilseeds_yield_12

UNITS: ton/tree

"Oilseeds_yield*_13" = IF Crop_rotation_cycle<13 THEN 0 ELSE Oilseeds_yield_13

UNITS: ton/tree

"Oilseeds_yield*_14" = IF Crop_rotation_cycle<14 THEN 0 ELSE Oilseeds_yield_14

UNITS: ton/tree

"Oilseeds_yield*_15" = IF Crop_rotation_cycle<15 THEN 0 ELSE Oilseeds_yield_15

UNITS: ton/tree

"Oilseeds_yield*_4" = IF Crop_rotation_cycle<4 THEN 0 ELSE Oilseeds_yield_4

UNITS: ton/tree

"Oilseeds_yield*_5" = IF Crop_rotation_cycle<5 THEN 0 ELSE Oilseeds_yield_5

UNITS: ton/tree

"Oilseeds_yield*_6" = IF Crop_rotation_cycle<6 THEN 0 ELSE Oilseeds_yield_6

UNITS: ton/tree

"Oilseeds_yield*_7" = IF Crop_rotation_cycle<7 THEN 0 ELSE Oilseeds_yield_7

UNITS: ton/tree

"Oilseeds_yield*_8" = IF Crop_rotation_cycle<8 THEN 0 ELSE Oilseeds_yield_8

UNITS: ton/tree

"Oilseeds_yield*_9" = IF Crop_rotation_cycle<9 THEN 0 ELSE Oilseeds_yield_9

UNITS: ton/tree

Palm_DBF_production_cost = (CPO_price*"IDR/USD"/"kL/ton_palm_oil"/"L/kL"+DBF_converting_cost*"IDR/USD"-"By-products_revenues")*Learning_effect_of_DBF_production

UNITS: IDR/L

Palm_oil_available_for_DBF = IF Sumba_DBF_production_capacity>0 THEN Palm_oil_stock_surplus ELSE 0

UNITS: ton/yr

Palm_oil_consumption_for_food_&_oleo_excluding_biodiesel = Fraction_palm_oil_consumption_for_food_&_oleo_excluding_biodiesel*Palm_oil_production

UNITS: ton/yr

Palm_oil_demand_for_biodiesel = Biodiesel_supply/"kL_biodiesel/_ton_palm_oil"

UNITS: ton/yr

Palm_oil_desired_stock_for_biodiesel = Palm_oil_consumption_for_biodiesel_&_DBF*Palm_oil_stock_sufficiency_period_for_biodiesel

UNITS: ton

Palm_oil_for_export = IF Sumba_DBF_production_capacity<=0 THEN MAX (0, Palm_oil_production*(1-Fraction_palm_oil_consumption_for_food_&_oleo_excluding_biodiesel)-Biodiesel_existing_mandate/"kL_biodiesel/_ton_palm_oil") ELSE Palm_oil_production*(1-DMO_palm_oil)

UNITS: ton/yr

Palm_oil_production = CPO_average_productivity*Oil_palm_plantation_area/Time_to_produce_palm_oil

UNITS: ton/yr

Palm_oil_stock_for_biodiesel_&_DBF(t) = Palm_oil_stock_for_biodiesel_&_DBF(t - dt) + (Palm_oil_supply_for_biodiesel_&_DBF - Palm_oil_consumption_for_biodiesel_&_DBF) * dt

INIT Palm_oil_stock_for_biodiesel_&_DBF = 0

UNITS: ton

INFLOWS:

Palm_oil_supply_for_biodiesel_&_DBF = (Palm_oil_production-Palm_oil_consumption_for_food_&_oleo_excluding_biodiesel-Palm_oil_for_export-Palm_oil_available_for_DBF)

UNITS: ton / yr

OUTFLOWS:

Palm_oil_consumption_for_biodiesel_&_DBF = Palm_oil_stock_for_biodiesel_&_DBF/Time_averaging_palm_oil_consumption_for_DBF

UNITS: ton / yr

Palm_oil_stock_sufficiency_period_for_biodiesel = 3/12

UNITS: year

Palm_oil_stock_surplus = IF (Palm_oil_stock_for_biodiesel_&_DBF-Palm_oil_desired_stock_for_biodiesel)/Time_averaging_palm_oil_consumption_for_DBF>0 THEN (Palm_oil_stock_for_biodiesel_&_DBF-Palm_oil_desired_stock_for_biodiesel)/Time_averaging_palm_oil_consumption_for_DBF ELSE 0

UNITS: ton/yr

Planting_area_per_block = INIT (Marginal_land_area_available_for_energy_crop)/Total_blocks_planted*Block_harvested

UNITS: ha

Planting_delay = IF Required_year_of_planting>0 AND Actual_year_of_planting_start>0 THEN Actual_year_of_planting_start-Required_year_of_planting ELSE -1

UNITS: year

Pongamia_DBF_production_cost = IF Sumba_DBF_production>0 THEN (Pongamia_oil_feedstock_cost+DBF_converting_cost*"IDR/USD"-"By-products_revenues")*Learning_effect_of_DBF_production *Learning_effect_of_Pongamia_oil_feedstock_production ELSE 0

UNITS: IDR/L

Pongamia_oil_feedstock_cost(t) = Pongamia_oil_feedstock_cost(t - dt) + (Changes_in_oil_feedstock_cost) * dt

INIT Pongamia_oil_feedstock_cost = 5000

UNITS: IDR/L

INFLOWS:

Changes_in_oil_feedstock_cost = Pongamia_oil_feedstock_cost*Pongamia_oil_feedstock_cost_growth_rate

UNITS: IDR/L/Years

Pongamia_oil_feedstock_cost_growth_rate = 0.001

UNITS: dmnl/yr

Pressure_from_BOT = IF "Balance_of_Trade_(BOT)"<0 THEN 1 ELSE 0

UNITS: dimensionless

Pressure_from_FPD = IF "Fuel_price_difference_(FPD)">0 THEN 1 ELSE 0

UNITS: dimensionless

Pressure_from_TR_to_land_development = MIN(1, "Technology_Technical_Readiness_(TR)")

UNITS: dimensionless

Price_ratio_of_biofuel_to_oil_fuel = IF National_DBF_production>0 THEN DBF_price/Oil_fuels_price ELSE Biodiesel_price/Oil_fuels_price

UNITS: dmnl

Remaining_biodiesel_capacity = (Biodiesel_production_capacity/Time_to_adjust_biodiesel_capacity-Discarding_biodiesel_capacity)

UNITS: kL/yr/yr

Required_oilseeds_per_DBF_plant = Desired_DBF_production_per_plant/"kL/ton_Pongamia_oil"/Oil_content_in_seeds/ Oil_feedstock_conversion*DBF_production_time

UNITS: ton

Required_year_of_planting = IF Desired_year_of_Pongamia_oil_feedstock_ready>0 AND Year_of_DBF_production_starts>0 AND Year_of_Pongamia_oilseeds_ready>0 THEN Desired_year_of_Pongamia_oil_feedstock_ready-(Year_of_DBF_production_starts-Year_of_Pongamia_oilseeds_ready)-Time_length_from_cultivation_to_first_harvest ELSE -1

UNITS: year

Sense_of_urgency_by_the_President(t) = Sense_of_urgency_by_the_President(t - dt) + (Increasing_in_urgency - Decreasing_in_urgency) * dt

INIT Sense_of_urgency_by_the_President = 1

UNITS: dimensionless

INFLOWS:

Increasing_in_urgency = IF Sense_of_urgency_by_the_President>0 AND Sense_of_urgency_by_the_President<1 THEN (((MAX(Pressure_from_BOT, Pressure_from_FPD))*(1-Weight_to_vision))+Future_vision_power*Weight_to_vision)/Time_to_change_urgency ELSE 0

UNITS: dmnl/yr

OUTFLOWS:

Decreasing_in_urgency = Sense_of_urgency_by_the_President/Time_to_change_urgency

UNITS: dmnl/yr

Sumba_accumulated_CO2_emissions(t) = Sumba_accumulated_CO2_emissions(t - dt) + (Sumba_CO2_emissions) * dt

INIT Sumba_accumulated_CO2_emissions = 0

UNITS: ton CO2e

INFLOWS:

Sumba_CO2_emissions = Net_CO2_emission_from_DBF+Net_CO2_emission_from_bioelectricity+CO2_emission_from_marginal_land_carbon_stock

UNITS: ton CO2e/yr

Sumba_added_DBF_capacity = IF Sumba_DBF_production_capacity< Sumba_oil_feedstock_for_DBF_production*Oil_feedstock_conversion THEN MAX(0, (Sumba_desired_DBF_capacity/Time_to_adjust_DBF_capacity-Sumba_remaining_DBF_capacity)) ELSE 0

UNITS: kL/yr/yr

Sumba_DBF_acumm_production(t) = Sumba_DBF_acumm_production(t - dt) + (Sumba_DBF_production) * dt

INIT Sumba_DBF_acumm_production = 0

UNITS: kL

INFLOWS:

Sumba_DBF_production = IF Sumba_oil_feedstock_for_DBF_production*Oil_feedstock_conversion>=Desired_DBF_production_per_plant AND Sumba_DBF_production_capacity>=Desired_DBF_production_per_plant THEN MIN(Sumba_oil_feedstock_for_DBF_production*Oil_feedstock_conversion, Sumba_DBF_production_capacity) ELSE 0

UNITS: kl/yr

Sumba_DBF_capacity_under_construction(t) = Sumba_DBF_capacity_under_construction(t - dt) + (Starting_DBF_construction - Completing_DBF_construction) * dt

INIT Sumba_DBF_capacity_under_construction = 0

UNITS: kL/yr

INFLOWS:

Starting_DBF_construction = Sumba_added_DBF_capacity

UNITS: kL/yr/yr

OUTFLOWS:

Completing_DBF_construction = Sumba_DBF_capacity_under_construction/DBF_plant_construction_time

UNITS: kL/yr/yr

Sumba_DBF_desired_stock = DBF_stock_sufficiency_period*Sumba_DBF_consumption

UNITS: kL

Sumba_DBF_for_export = IF Sumba_liquid_fuel_import_demand=0 THEN MIN (Sumba_DBF_production-Sumba_liquid_fuel_demand, Sumba_DBF_surplus) ELSE 0

UNITS: kl/yr

Sumba_DBF_production_capacity(t) = Sumba_DBF_production_capacity(t - dt) + (Completing_DBF_construction - Discarding_DBF_capacity) * dt

INIT Sumba_DBF_production_capacity = 0

UNITS: kL/yr

INFLOWS:

Completing_DBF_construction = Sumba_DBF_capacity_under_construction/DBF_plant_construction_time

UNITS: kL/yr/yr

OUTFLOWS:

Discarding_DBF_capacity = Sumba_DBF_production_capacity/DBF_capacity_life_time

UNITS: kL/yr/yr

Sumba_DBF_stock(t) = Sumba_DBF_stock(t - dt) + (Sumba_DBF_supply - Sumba_DBF_consumption) * dt

INIT Sumba_DBF_stock = 0

UNITS: kL

INFLOWS:

Sumba_DBF_supply = Sumba_DBF_production-Sumba_DBF_for_export

UNITS: kl/yr

OUTFLOWS:

Sumba_DBF_consumption = IF Sumba_DBF_production>=Sumba_liquid_fuel_demand THEN Sumba_liquid_fuel_demand ELSE Sumba_DBF_stock/Time_to_average_Sumba_DBF_stock

UNITS: kL/yr

Sumba_DBF_surplus = IF Sumba_DBF_stock>Sumba_DBF_desired_stock THEN ((Sumba_DBF_stock-Sumba_DBF_desired_stock)/Time_to_average_Sumba_DBF_surplus) ELSE 0

UNITS: kl/yr

Sumba_desired_DBF_capacity = IF TIME>=Desired_year_of_Pongamia_oil_feedstock_ready-DBF_plant_construction_time AND Desired_year_of_Pongamia_oil_feedstock_ready>0 THEN Sumba_oil_feedstock_for_DBF_production ELSE 0

UNITS: kl/yr

Sumba_developed_marginal_land_area(t) = Sumba_developed_marginal_land_area(t - dt) + (Marginal_lland_development_rate) * dt

INIT Sumba_developed_marginal_land_area = 0

UNITS: ha

INFLOWS:

Marginal_lland_development_rate = IF TIME<STARTTIME+Time_to_develop_land THEN 0 ELSE MAX(0, Marginal_land_area_available_for_energy_crop)/Time_to_develop_land

UNITS: Hectares/Years

"Sumba_GRDP_increase_from_DBF,_oilseeds,_and_woodfuel" = Sumba_DBF_production*"DBF_price_IDR/kL"/"IDR/USD"*"L/kL"+Sumba_oilseeds_for_harvest*Oilseeds_price+Sumba_woodfuel_for_harvest/Woodfuel_consumption_time*Woodfuel_price

UNITS: US $ / yr

Sumba_liquid_fuel_demand = GRAPH(TIME)

(2018.00, 91595), (2019.00, 96175), (2020.00, 100983), (2021.00, 106033), (2022.00, 111334), (2023.00, 116901), (2024.00, 122746), (2025.00, 128883), (2026.00, 135327), (2027.00, 142094), (2028.00, 149198), (2029.00, 156658), (2030.00, 164491), (2031.00, 172716), (2032.00, 181352), (2033.00, 190419), (2034.00, 199940), (2035.00, 209937), (2036.00, 220434), (2037.00, 231456), (2038.00, 243029), (2039.00, 255180), (2040.00, 267939), (2041.00, 281336), (2042.00, 295403), (2043.00, 310173), (2044.00, 325681), (2045.00, 341966)

UNITS: kL/yr

Sumba_liquid_fuel_import_demand = IF Sumba_DBF_production>Sumba_liquid_fuel_demand THEN 0 ELSE Sumba_liquid_fuel_demand-Sumba_DBF_production

UNITS: kl/yr

"Sumba_liquid_fuel_self-sufficiency" = (Sumba_liquid_fuel_demand-Sumba_liquid_fuel_import_demand)/Sumba_liquid_fuel_demand

UNITS: dimensionless

Sumba_oil_feedstock_for_DBF_production = Sumba_oilseeds_feedstock*Oil_content_in_seeds*"kL/ton_Pongamia_oil"

UNITS: kL/yr

Sumba_oilseeds_feedstock = Sumba_oilseeds_for_harvest*Marginal_land_feedstock_management

UNITS: ton/yr

Sumba_oilseeds_for_harvest = (Oilseeds_4+Oilseeds_5+Oilseeds_6+Oilseeds_7+Oilseeds_8+Oilseeds_9+Oilseeds_10+Oilseeds_11+Oilseeds_12+Oilseeds_13+Oilseeds_14+Oilseeds_15)

UNITS: ton / yr

Sumba_remaining_DBF_capacity = (Sumba_DBF_production_capacity/Time_to_adjust_DBF_capacity-Discarding_DBF_capacity)

UNITS: kL/yr/yr

Sumba_woodfuel_for_harvest = IF TIME>=Actual_year_of_planting_start+Crop_rotation_cycle AND Actual_year_of_planting_start>0 THEN Woodfuel_yield_per_tree*Trees_per_block ELSE 0

UNITS: ton

Supports_on_marginal_land_development_time = (Infrastructure_readiness*Land_status_clarity*Landowners'_willingness_to_cultivate*Local_government_commitment)*(1-Weight_to_pressure_from_TR_on_land_development)+Pressure_from_TR_to_land_development*Weight_to_pressure_from_TR_on_land_development

UNITS: dimensionless

Supports_on_technology_readiness = Sense_of_urgency_by_the_President

UNITS: dmnl

"Technology_Technical_Readiness_(TR)"(t) = "Technology_Technical_Readiness_(TR)"(t - dt) + (TR_progress_rate) * dt

INIT "Technology_Technical_Readiness_(TR)" = 0.5

UNITS: dimensionless

INFLOWS:

TR_progress_rate = IF TR_difference<0 THEN TR_difference*-1*Investment_interval/Time_to_progress_TR ELSE 0

UNITS: dmnl/yr

The_Regent's_commitment_strength_for_energy_crop = Government_support_for_the_Regent's_commitment

UNITS: dimensionless

Time_averaging_biodiesel_consumption = 1

UNITS: year

Time_averaging_national_liquid_biofuel_surplus = 1

UNITS: yr

Time_averaging_palm_oil_consumption_for_DBF = 1

UNITS: year

Time_for_private_landowners'_to_understand = 1

UNITS: year

Time_length_from_cultivation_to_first_harvest = 3

UNITS: year

Time_to_adjust_biodiesel_capacity = 1

UNITS: year

Time_to_adjust_DBF_capacity = 1

UNITS: year

Time_to_average_national_liquid_biofuel_for_consumption = 1

UNITS: year

Time_to_average_Sumba_DBF_stock = 1

UNITS: year

Time_to_average_Sumba_DBF_surplus = 1

UNITS: year

Time_to_change_local_government_commitment = 1

UNITS: year

Time_to_change_urgency = 1

UNITS: year

Time_to_develop_land = Expected_time_to_develop_land/Supports_on_marginal_land_development_time

UNITS: yr

Time_to_grow = 1

UNITS: year

Time_to_increase_land_certification = 1

UNITS: year

Time_to_produce_palm_oil = 1

UNITS: year

Time_to_progress_infrastructure = 1

UNITS: year

Time_to_progress_TR = Expected_time_to_progress_TR/Supports_on_technology_readiness

UNITS: yr

Time_to_stocking_green_biomass = 1

UNITS: yr

"Ton_CO2e_/_ton_C" = 44/12

UNITS: ton CO2e / ton C

Total_blocks_planted = Crop_rotation_cycle/"harvesting_time/block"

UNITS: block

TR_difference = "Technology_Technical_Readiness_(TR)"-Desired_TR

UNITS: dimensionless

TR_Investment_balance = Accumulated_TR_investment-Investment_required_for_TR

UNITS: %

Trees_1(t) = Trees_1(t - dt) + (Planting_&_growing_1 - Growing_2) * dt

INIT Trees_1 = 0

UNITS: ton

INFLOWS:

Planting_&_growing_1 = Trees_per_block*Growth_year_1/Time_to_grow

UNITS: ton / yr

OUTFLOWS:

Growing_2 = Trees_1/Time_to_grow

UNITS: ton / yr

Trees_10(t) = Trees_10(t - dt) + (Growing_10 + Planting_&_growing_10 - Oilseeds_10 - Growing_11) * dt

INIT Trees_10 = 0

UNITS: ton

INFLOWS:

Growing_10 = Trees_9/Time_to_grow

UNITS: ton / yr

Planting_&_growing_10 = Growth_year_10*Trees_per_block/Time_to_grow

UNITS: ton / yr

OUTFLOWS:

Oilseeds_10 = IF TIME<Actual_year_of_planting_start+9 OR Actual_year_of_planting_start=-1 THEN 0 ELSE MAX(0,"Oilseeds_yield*_10"*Trees_per_block/Time_to_grow)

UNITS: ton / yr

Growing_11 = Trees_10/Time_to_grow

UNITS: ton / yr

Trees_11(t) = Trees_11(t - dt) + (Growing_11 + Planting_&_growing_11 - Oilseeds_11 - Growing_12) * dt

INIT Trees_11 = 0

UNITS: ton

INFLOWS:

Growing_11 = Trees_10/Time_to_grow

UNITS: ton / yr

Planting_&_growing_11 = Growth_year_11*Trees_per_block/Time_to_grow

UNITS: ton / yr

OUTFLOWS:

Oilseeds_11 = IF TIME<Actual_year_of_planting_start+10 OR Actual_year_of_planting_start=-1 THEN 0 ELSE MAX(0,"Oilseeds_yield*_11"*Trees_per_block/Time_to_grow)

UNITS: ton / yr

Growing_12 = Trees_11/Time_to_grow

UNITS: ton / yr

Trees_12(t) = Trees_12(t - dt) + (Planting_&_growing_12 + Growing_12 - Growing_13 - Oilseeds_12) * dt

INIT Trees_12 = 0

UNITS: ton

INFLOWS:

Planting_&_growing_12 = Growth_year_12*Trees_per_block/Time_to_grow

UNITS: ton / yr

Growing_12 = Trees_11/Time_to_grow

UNITS: ton / yr

OUTFLOWS:

Growing_13 = Trees_12/Time_to_grow

UNITS: ton / yr

Oilseeds_12 = IF TIME<Actual_year_of_planting_start+11 OR Actual_year_of_planting_start=-1 THEN 0 ELSE MAX(0,"Oilseeds_yield*_12"*Trees_per_block/Time_to_grow)

UNITS: ton / yr

Trees_13(t) = Trees_13(t - dt) + (Planting_&_growing_13 + Growing_13 - Oilseeds_13 - Growing_14) * dt

INIT Trees_13 = 0

UNITS: ton

INFLOWS:

Planting_&_growing_13 = Growth_year_13*Trees_per_block/Time_to_grow

UNITS: ton / yr

Growing_13 = Trees_12/Time_to_grow

UNITS: ton / yr

OUTFLOWS:

Oilseeds_13 = IF TIME<Actual_year_of_planting_start+12 OR Actual_year_of_planting_start=-1 THEN 0 ELSE MAX(0,"Oilseeds_yield*_13"*Trees_per_block/Time_to_grow)

UNITS: ton / yr

Growing_14 = Trees_13/Time_to_grow

UNITS: ton / yr

Trees_14(t) = Trees_14(t - dt) + (Planting_&_growing_14 + Growing_14 - Oilseeds_14 - Growing_15) * dt

INIT Trees_14 = 0

UNITS: ton

INFLOWS:

Planting_&_growing_14 = Growth_year_14*Trees_per_block/Time_to_grow

UNITS: ton / yr

Growing_14 = Trees_13/Time_to_grow

UNITS: ton / yr

OUTFLOWS:

Oilseeds_14 = IF TIME<Actual_year_of_planting_start+13 OR Actual_year_of_planting_start=-1 THEN 0 ELSE MAX(0,"Oilseeds_yield*_14"*Trees_per_block/Time_to_grow)

UNITS: ton / yr

Growing_15 = Trees_14/Time_to_grow

UNITS: ton / yr

Trees_15(t) = Trees_15(t - dt) + (Planting_&_growing_15 + Growing_15 - Oilseeds_15 - Stocking_green_biomass) * dt

INIT Trees_15 = 0

UNITS: ton

INFLOWS:

Planting_&_growing_15 = Growth_year_15*Trees_per_block/Time_to_grow

UNITS: ton / yr

Growing_15 = Trees_14/Time_to_grow

UNITS: ton / yr

OUTFLOWS:

Oilseeds_15 = IF TIME<Actual_year_of_planting_start+14 OR Actual_year_of_planting_start=-1 THEN 0 ELSE MAX(0,"Oilseeds_yield*_15"*Trees_per_block/Time_to_grow)

UNITS: ton / yr

Stocking_green_biomass = Trees_15/Time_to_stocking_green_biomass

UNITS: ton / yr

Trees_2(t) = Trees_2(t - dt) + (Growing_2 + Planting_&_growing_2 - Growing_3) * dt

INIT Trees_2 = 0

UNITS: ton

INFLOWS:

Growing_2 = Trees_1/Time_to_grow

UNITS: ton / yr

Planting_&_growing_2 = Growth_year_2*Trees_per_block/Time_to_grow

UNITS: ton / yr

OUTFLOWS:

Growing_3 = Trees_2/Time_to_grow

UNITS: ton / yr

Trees_3(t) = Trees_3(t - dt) + (Growing_3 + Planting_&_growing_3 - Growing_4) * dt

INIT Trees_3 = 0

UNITS: ton

INFLOWS:

Growing_3 = Trees_2/Time_to_grow

UNITS: ton / yr

Planting_&_growing_3 = Growth_year_3*Trees_per_block/Time_to_grow

UNITS: ton / yr

OUTFLOWS:

Growing_4 = Trees_3/Time_to_grow

UNITS: ton / yr

Trees_4(t) = Trees_4(t - dt) + (Growing_4 + Planting_&_growing_4 - Growing_5 - Oilseeds_4) * dt

INIT Trees_4 = 0

UNITS: ton

INFLOWS:

Growing_4 = Trees_3/Time_to_grow

UNITS: ton / yr

Planting_&_growing_4 = Growth_year_4*Trees_per_block/Time_to_grow

UNITS: ton / yr

OUTFLOWS:

Growing_5 = Trees_4/Time_to_grow

UNITS: ton / yr

Oilseeds_4 = IF TIME<Actual_year_of_planting_start+3 OR Actual_year_of_planting_start=-1 THEN 0 ELSE MAX(0,"Oilseeds_yield*_4"*Trees_per_block/Time_to_grow)

UNITS: ton / yr

Trees_5(t) = Trees_5(t - dt) + (Growing_5 + Planting_&_growing_5 - Oilseeds_5 - Growing_6) * dt

INIT Trees_5 = 0

UNITS: ton

INFLOWS:

Growing_5 = Trees_4/Time_to_grow

UNITS: ton / yr

Planting_&_growing_5 = Growth_year_5*Trees_per_block/Time_to_grow

UNITS: ton / yr

OUTFLOWS:

Oilseeds_5 = IF TIME<Actual_year_of_planting_start+4 OR Actual_year_of_planting_start=-1 THEN 0 ELSE MAX(0,"Oilseeds_yield*_5"*Trees_per_block/Time_to_grow)

UNITS: ton / yr

Growing_6 = Trees_5/Time_to_grow

UNITS: ton / yr

Trees_6(t) = Trees_6(t - dt) + (Planting_&_growing_6 + Growing_6 - Growing_7 - Oilseeds_6) * dt

INIT Trees_6 = 0

UNITS: ton

INFLOWS:

Planting_&_growing_6 = Growth_year_6*Trees_per_block/Time_to_grow

UNITS: ton / yr

Growing_6 = Trees_5/Time_to_grow

UNITS: ton / yr

OUTFLOWS:

Growing_7 = Trees_6/Time_to_grow

UNITS: ton / yr

Oilseeds_6 = IF TIME<Actual_year_of_planting_start+5 OR Actual_year_of_planting_start=-1 THEN 0 ELSE MAX(0,"Oilseeds_yield*_6"*Trees_per_block/Time_to_grow)

UNITS: ton / yr

Trees_7(t) = Trees_7(t - dt) + (Planting_&_growing_7 + Growing_7 - Oilseeds_7 - Growing_8) * dt

INIT Trees_7 = 0

UNITS: ton

INFLOWS:

Planting_&_growing_7 = Growth_year_7*Trees_per_block/Time_to_grow

UNITS: ton / yr

Growing_7 = Trees_6/Time_to_grow

UNITS: ton / yr

OUTFLOWS:

Oilseeds_7 = IF TIME<Actual_year_of_planting_start+6 OR Actual_year_of_planting_start=-1 THEN 0 ELSE MAX(0,"Oilseeds_yield*_7"*Trees_per_block/Time_to_grow)

UNITS: ton / yr

Growing_8 = Trees_7/Time_to_grow

UNITS: ton / yr

Trees_8(t) = Trees_8(t - dt) + (Growing_8 + Planting_&_growing_8 - Oilseeds_8 - Growing_9) * dt

INIT Trees_8 = 0

UNITS: ton

INFLOWS:

Growing_8 = Trees_7/Time_to_grow

UNITS: ton / yr

Planting_&_growing_8 = Growth_year_8*Trees_per_block/Time_to_grow

UNITS: ton / yr

OUTFLOWS:

Oilseeds_8 = IF TIME<Actual_year_of_planting_start+7 OR Actual_year_of_planting_start=-1 THEN 0 ELSE MAX(0,"Oilseeds_yield*_8"*Trees_per_block/Time_to_grow)

UNITS: ton / yr

Growing_9 = Trees_8/Time_to_grow

UNITS: ton / yr

Trees_9(t) = Trees_9(t - dt) + (Growing_9 + Planting_&_growing_9 - Oilseeds_9 - Growing_10) * dt

INIT Trees_9 = 0

UNITS: ton

INFLOWS:

Growing_9 = Trees_8/Time_to_grow

UNITS: ton / yr

Planting_&_growing_9 = Growth_year_9*Trees_per_block/Time_to_grow

UNITS: ton / yr

OUTFLOWS:

Oilseeds_9 = IF TIME<Actual_year_of_planting_start+8 OR Actual_year_of_planting_start=-1 THEN 0 ELSE MAX(0,"Oilseeds_yield*_9"*Trees_per_block/Time_to_grow)

UNITS: ton / yr

Growing_10 = Trees_9/Time_to_grow

UNITS: ton / yr

Trees_per_block = Trees_per_Ha*Planting_area_per_block

UNITS: tree

Trees_per_Ha = 350

UNITS: tree/ha

Weight_to_pressure_from_TR_on_land_development = 0.2

UNITS: dimensionless

Weight_to_vision = 1

UNITS: dimensionless

Woodfuel_calor = 20/3.6

UNITS: MWh/ton

Woodfuel_CO2_emission_from_bioelectricity = Sumba_woodfuel_for_harvest/Averaging_consumption_time*Woodfuel_electricity_CO2_emission_factor

UNITS: ton CO2e/yr

Woodfuel_consumption_time = 1

UNITS: year

Woodfuel_electricity_CO2_emission_factor = 0.0143

UNITS: ton CO2e/ton

Woodfuel_price = 50

UNITS: US $/ton

Woodfuel_yield_per_tree = 10e-3

UNITS: ton/tree

Year_of_DBF_production_starts = IF Sumba_DBF_production > 0 AND PREVIOUS(SELF, -1) < 0 THEN TIME ELSE PREVIOUS(SELF, -1)

UNITS: yr

Year_of_Pongamia_oilseeds_ready = IF Sumba_oilseeds_feedstock > 0 AND PREVIOUS(SELF, -1) < 0 THEN TIME ELSE PREVIOUS(SELF, -1)

UNITS: year

Year_of_technology_commercially_ready = IF Year_of_technology_technically_ready=-1 THEN -1 ELSE Year_of_technology_technically_ready+"Expected_time_of_post-technical_readiness"

UNITS: year

Year_of_technology_technically_ready = IF "Technology_Technical_Readiness_(TR)">=Desired_TR-0.0025 AND PREVIOUS(SELF, -1) < 0 THEN TIME ELSE PREVIOUS(SELF, -1)

UNITS: year

{ The model has 350 (350) variables (array expansion in parens).

In root model and 0 additional modules with 10 sectors.

Stocks: 32 (32) Flows: 65 (65) Converters: 253 (253)

Constants: 104 (104) Equations: 214 (214) Graphicals: 14 (14)

There are also 30 expanded macro variables.

}