RESEARCH PROGRAM ON
Forests, Trees and Agroforestry

Bioenergy for landscape restoration and livelihoods

Re-creating energy-smart ecosystems on degraded landscapes

Editors
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Center for International Forestry Research (CIFOR)

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Foreword

Indonesia has an estimated 14 million hectares of degraded land that provides little benefit for people due to its reduced provision of goods and services, or for the climate owing to its diminished capacity to absorb carbon. Following the Paris Agreement in 2015, through its Nationally Determined Contribution (NDC), Indonesia has committed to reducing its greenhouse gas (GHG) emissions by 29 percent compared to a business-as usual scenario by 2030. The country has also committed to new and renewable energy making up 23 percent of its national energy mix by 2025. Bioenergy has an important role to play in realizing these commitments.

Restoration of degraded and underutilized land using biofuel-producing species in climate-smart agroforestry systems can create vast bioenergy potential without causing competition for land required for other purposes, such as food production or nature conservation. Due to high net primary productivity, this presents an important opportunity for Indonesia to develop modern sustainable bioenergy while pursuing ambitious landscape restoration initiatives, such as its NDC target of restoring 14 million hectares of degraded land by 2030.

With support from the Republic of Korea, over the past six years, CIFOR, the Centre for Forest Biotechnology and Tree Improvement under Indonesia's Ministry of Environment and Forestry, and partners including the Mulawarman University Tropical Rainforest Reforestation Centre, Muhammadiyah University in Palangkaraya and the Sriwijaya University Centre of Excellence on Peatland Research have been studying the potential of bioenergy crops for restoring degraded land in Indonesia. The studies presented in this book show their findings in the contexts of national and global restoration goals, such as Indonesia's NDC, the Bonn Challenge and the United Nations Decade on Ecosystem Restoration.

Covering a wide range of topics relating to bioenergy production, this book discusses government policies and initiatives in recent decades, spatial assessments of degraded land available for bioenergy production, and landowners' perceptions of bioenergy crops and landscape restoration. Its species-specific information on '*nyamplung*', pongamia and bamboo provides valuable insights for farmers, community groups, small and medium enterprises as well as policymakers.

Evidence presented in this book acknowledges land scarcity and the need for biofuel production to avoid competition with agriculture and expansion into forested areas, while demonstrating a win-win solution for people and the planet. Growing biomass for energy on degraded and underutilized land is certainly a more beneficial land use strategy, considering its potential for enhancing soil fertility, and improving farm production, incomes and biodiversity while supporting climate and sustainable development goals.

Robert Nasi
Director General, CIFOR
Managing Director, CIFOR-ICRAF

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List of acronyms

ACE	ASEAN Center for Energy
ACTI	Advisory Committee on Technology Innovation
ADB	Asian Development Bank
ANOVA	Analysis of variance
APL	Areal Penggunaan Lain (areas for other land uses)
APROBI	Asosiasi Produsen Biofuel Indonesia (Indonesian Biofuel Producers Association)
ARE	Alliance for Rural Electrification
BAPPENAS	Badan Perencanaan Pembangunan Nasional (Ministry of National Development Planning of the Republic of Indonesia)
BBN	*Bahan bakar nabati* (biofuel)
BBPPSDLP	Balai Besar Penelitian dan Pengembangan Sumberdaya Lahan Pertanian
BIRU	Biogas Rumah (Indonesia's domestic biogas programme)
BPDLH	Badan Pengelola Dana Lingkungan Hidup (Indonesia's Environment Fund Management Agency)
BPPT	Badan Pengkajian dan Penerapan Teknologi (Technology Assessment and Application Agency)
BPS	Badan Pusat Statistik (Statistics Indonesia)
BRG	Badan Restorasi Gambut (Peatland Restoration Agency)
BRGM	Badan Restorasi Gambut dan Mangrove (Peatland and Mangrove Restoration Agency)
BSN	Badan Standarisasi Nasional (Indonesia's National Standardization Agency)
BVG	Buntoi Village Government
CABI	Centre for Agriculture and Bioscience International
CAIT	Climate Analysis Indicators Tool
CBD	Convention on Biological Diversity
CCO	Constrained constructive optimization
CCO	Crude calophyllum oil
CFBTIRD	Center for Forest Biotechnology and Tree Improvement Research and Development
CIFOR	Center for International Forestry Research
CJO	Crude jatropha oil
CNO	Crude *nyamplung* oil
CPI	Clean Power Indonesia
CPO	Crude palm oil
CRP-FTA	CGIAR Research Program on Forests, Trees and Agroforestry
DEN	Dewan Energi Nasional (Indonesia's National Energy Council)
DIPSH	Direktorat Inventarisasi dan Pemantauan Sumberdaya Hutan (Indonesia's Directorate of Forest Resources Inventory and Monitoring)

DME	Desa mandiri energi (energy self-sufficient village)
DPEPDA	Direktorat Perencanaan dan Evaluasi Pengendalian Daerah Aliran Sungai (Indonesia's Directorate of Watershed Control Planning and Evaluation)
DPPKH	Direktorat Pengukuhan dan Penatagunaan Kawasan Hutan (Indonesia's Directorate of Forest Estate Gazettement and Administration)
EFBs	Empty fruit bunches
EJ	Exajoule
ESDM	Energi dan Sumber Daya Mineral (Ministry of Energy and Mineral Resources)
FAME	Fatty acid methyl esters
FAO	Food and Agriculture Organization of the United Nations
FGD	Focus group discussion
FLR	Forest landscape restoration
FMU	Forest management unit
FOERDIA	Forestry and Environmental Research, Development and Innovation Agency
GAIN	Global Agriculture Information Network
GCA	General combining ability
GDP	Gross domestic product
GGGI	Global Green Growth Institute
GHG	Greenhouse gas
GIS	Geographic information system
GJ	Gigajoule
GoI	Government of Indonesia
HDI	Human Development Index
HKM	Hutan Kemasyarakatan (community forest)
HL	Hutan Lindung (protection forest)
HP	Hutan Produksi (production forest)
HPK	Hutan Produksi Konversi (convertible production forest)
HTE	Hutan Tanaman Energi (energy crop forest)
ICCC	Indonesia Climate Change Center
ICRAF	World Agroforestry Centre
IUCN	International Union for Conservation of Nature
IDBP	Indonesia Domestic Biogass Programme
IEA	International Energy Agency
IEEE	Institute of Electrical and Electronics Engineers
IESR	Institute for Essential Services Reform
INBAR	International Network for Bamboo and Rattan
IPCC	Intergovernmental Panel on Climate Change
IPHHBK	Izin Pemungutan Hasil Hutan Bukan Kayu (non-timber forest product utilization permit)
IPP	Independent power producer
IRENA	International Renewable Energy Agency
IUCN	International Union for Conservation of Nature

IUPHHK-HTR	Izin Usaha Pemanfaatan Hasil Hutan Kayu pada Hutan Tanaman Rakyat (community plantation forest timber utilization business permit)
KFS	Korea Forest Service
KGPA	Korea Green Promotion Agency
KHDTK	Kawasan Hutan dengan Tujuan Khusus (special purpose forest estate)
KHDTK-HPPBS	Kawasan Hutan dengan Tujuan Khusus-Hutan Penelitian dan Pendidikan Bukit Soeharto (special purpose forest estate - Bukit Soeharto Research and Education Forest)
KPA	Kawasan Pelestarian Alam (nature conservation area)
KSA	Kawasan Suaka Alam (nature reserve area)
LAS	Leica Application Suite
LIPI	Lembaga Ilmu Pengetahuan Indonesia (Indonesian Institute of Sciences)
LULUCF	Land Use, Land-Use Change and Forestry
MCA	Millennium Challenge Account
MFC	Microbial fuel cell
MoEF	Ministry of Environment and Forestry
MJ	Megajoule
MoU	Memorandum of Understanding
MSW	Municipal solid waste
$MtCO_2e$	Metric tons of carbon dioxide equivalent
MW	Megawatt
NDC	Nationally Determined Contribution
NFTs	Nitrogen fixing trees
NGO	Non-governmental organizations
NIFoS	National Institute of Forest Sciences
NPK	nitrogen (N), phosphorus (P) and potassium (K)
NPV	Net present value
NRE	New and renewable energy
NTFP	Non-timber forest product
P3BPTH	Pusat Penelitian dan Pengembangan Bioteknologi dan Pemuliaan Tanaman Hutan (Indonesia’s Research and Development Centre for Forest Biotechnology and Tree Improvement)
PLN	Perusahaan Listrik Negara (Indonesia’s state-owned electricity company)
PMPs	Permanent measurement plots
POME	Palm oil mill effluent
PPA	Power purchasing agreement
PSO	Public service obligation
PSS	Provenance seed stand
RAPD	Random Amplified Polymorphic DNA
RCCO	Refined crude calophyllum oil
REDD+	Reducing Emissions from Deforestation and forest Degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries
RePPProT	Regional Physical Planning Programme for Transmigration

RNI	Rajawali Nusantara Indonesia
RUEN	Rencana Umum Energi Nasional (National Energy Plan)
RUKN	Rencana Umum Ketenagalistrikan Nasional
RU	Refinery Unit
SAS	Statistical analysis system
SDGs	Sustainable Development Goals
Setkab	Sekretariat Kabinet Republik Indonesia (Cabinet Secretariat of the Republic of Indonesia)
SMEs	Small and medium enterprises
SNI	Standar Nasional Indonesia (Indonesian National Standard)
SWOT	Strengths, weaknesses, opportunities and threats
UKNP	Ujung Kulon National Park
UN	United Nations
UNDP	United Nations Development Programme
UNCCD	United Nations Convention to Combat Desertification
UNFCCC	United Nations Framework Convention on Climate Change
USA	United States of America
VGF	Viability gap funding
WCO	Waste cooking oil
WEC	World Energy Council
WFPS	Water-filled pore space
WNT	West Nusa Tenggara Province
WRI	World Resources Institute
WWF	World Wide Fund for Nature

Executive summary

Planting bioenergy crops on degraded land can help Indonesia meet its landscape restoration targets and satisfy its growing energy demand. Bioenergy plantations can sequestrate and store carbon, support biodiversity and provide livelihood opportunities in remote and isolated regions. Restoring vast areas of degraded land is a costly undertaking, and due to their limited productivity has so far proved unattractive to investors. Establishing bioenergy plantations on degraded land can help offset the high costs involved in meeting land restoration targets without the need to compete for land with food production and can curb unsustainable wood extraction from natural forests. It can also contribute to global restoration goals such as the UN Decade on Ecosystem Restoration and the Bonn Challenge, as well as Indonesia's Nationally Determined Contribution (NDC) and commitment to restore 14 million hectares of degraded land by 2030.

However, restoring land by growing bioenergy crops is still in its infancy and requires sound science, policy support, practice, guidance and monitoring. Identifying the right trees for the right purpose in the right place, and respecting local rights are key to successful bioenergy plantation development. With support from, and in collaboration with the Republic of Korea's National Institute of Forest Science (NiFoS), Indonesia's Ministry of Environment and Forestry and local partners, CIFOR has been undertaking a range of research activities to address the knowledge-implementation gap. These activities include geospatial analysis and mapping; stakeholder perception analysis; testing, monitoring growth and estimating yield of a variety of tree species on a wide range of degraded landscapes; and other potential environmental and economic benefits. This book highlights insights and key findings of research over the past six years of project implementation that could be helpful to farmers, community groups, small and medium enterprises as well as policymakers.

Chapter 2 by Widayati et al. investigates bioenergy initiatives and applications in Indonesia, and emphasizes the need for enabling conditions, policies, financing and incentives.

Chapter 3 by Jaung et al. uses spatial analysis to estimate the extent of degraded lands suitable for growing biodiesel and biomass species, and discusses two production, growth model and carbon stock scenarios.

Chapter 4 by Artati et al. examines landowners' perceptions of bioenergy tree species and their preferences for land restoration. It provides recommendations for involving landowners in the development of bioenergy crops in restoring degraded lands.

Chapter 5 by Shin et al. identifies bioenergy species suitable for different conditions, provides comprehensive information on ideal growing conditions for and energy outputs from bioenergy tree species, and recommends strategies for improving bioenergy production.

Chapter 6 by Rahman et al. examines the socioeconomic and environmental benefits of *Calophyllum inophyllum*-based bioenergy production in different agroforestry systems combined with rice, maize, peanuts and honey.

Chapter 7 by Maimunah et al. explores, assesses and compares the survival and growth performance of potential bioenergy species on burned and degraded peatlands, and shows species performing better in agroforestry systems than in monocultures.

Chapter 8 by Shin et al. investigates and assesses soil macrofauna biodiversity and changes in soil fauna patterns in a burnt peatland area being restored with the establishment of a bioenergy crop plantation.

Chapter 9 by Leksono et al. reports on the growth performance of *nyamplung* on previously burned land and shows the species adapting robustly to low fertility and acidic soils, enhancing soil properties and attracting birds and insects while providing a source of renewable energy.

Chapter 10 by Sharma et al. discusses the benefits and characteristics of bamboo as a potential bioenergy species, and the potential challenges associated with cultivating and managing bamboo plantations.

Chapter 11 by Hasnah et al. investigates a solvent method for extracting oil from *Pongamia pinatta* seeds. It shows extraction methods, extraction machines and genetic factors can all influence oil production.

Chapter 12 by Leksono et al. explores the potential of *Calophyllum inophyllum* for green energy production and restoration of degraded lands in Indonesia. It shows *Calophyllum inophyllum* agroforestry systems on degraded land being socially, economically and environmentally favourable for local communities.

Chapter 13 by Leksono et al. shows the nitrogen-fixing tree *Pongamia pinatta* being an ideal candidate for restoring degraded land and providing multiple economic benefits. It shows the multipurpose species having significant potential to help Indonesia meet its energy demands while restoring degraded land.

Lastly, Chapter 14 by Wahono et al. investigates a biomass gasification project and suggests a community biomass-based power generation system for electrification in inaccessible rural areas.

CHAPTER 1

An introduction to bioenergy and landscape restoration

Himlal Baral, Budi Leksono and Mihyun Seol

Abstract: Land degradation is becoming a global challenge, with Indonesia being no exception. Rising populations and their associated food and biomaterial demands have accelerated the conversion of forests for other land uses; a trend that persists in many parts of the world. Forest landscape restoration (FLR) is being promoted as a means for reversing land degradation while providing multiple products and services, including bioenergy. FLR using biofuel-friendly trees under climate smart agroforestry practices and utilizing fruits, nuts and biomass for energy could solve multiple issues by turning unproductive degraded lands into productive landscapes; preventing further conversion of natural vegetation for other uses; compensating for the high initial investments required for FLR; and providing multiple ecosystem services, including climate regulation. The chapters in this book investigate multiple issues associated with FLR and bioenergy, such as policy analysis, geospatial assessment for identifying land suitability, farmers' perceptions and species-specific details useful for land managers, planners and policymakers.

Keywords: Bioenergy, sustainability, landscape restoration, carbon

1.1 Introduction

Healthy forests and landscapes are essential for people and the planet, not only because of their contributions to the myriad ecosystem goods and products essential to local well-being, but also their multiple ecosystem services. These services include their natural capacity to store carbon, support biodiversity, regulate water and maintain soil health. According to Indonesia's Ministry of Environment and Forestry (MoEF), the country has more than 14 million hectares of degraded land, which includes two million hectares of degraded peatlands that play a vital role in climate mitigation through their vast stores of carbon. With such a large area of degraded land, Indonesia's need for forest landscape restoration (FLR) is inevitable.

Meanwhile, Indonesia's energy demand is growing rapidly in line with its population and economic growth. This trend is likely to continue into the foreseeable future due to the government's ambitious plans to provide energy to the entire population through its National Energy Policy (*Kebijakan Energi Nasional*) as stipulated under Government Regulation No. 79/2014. Following the Paris Agreement in 2015, through its Nationally Determined Contribution (NDC), Indonesia has committed to reducing its greenhouse gas (GHG) emissions by 29 percent compared to a business-as usual scenario by 2030. The country has also committed to new and renewable energy making up 23 percent of its national energy mix by 2025. Bioenergy production is one of the strategic measures aimed at achieving these targets.

The existence of vast areas of degraded land and ever-increasing demand for energy can pose both challenges and opportunities. FLR is a costly undertaking and a key obstacle to achieving its targets is the lack of financial resources to support FLR activities. Meanwhile, increasing energy demand and the promotion of biomass energy could exert further pressures on the country's remaining natural forests and food production; something known as the food-energy-environment trilemma. However, if designed and implemented appropriately, FLR can produce multiple goods and services including wood, biomass for energy, biomaterials, agri-food products and essential oils, as well as economic and social benefits while supporting nature conservation. For example, restoration of degraded and underutilized land using biofuel-producing species in climate-smart agroforestry systems can create vast bioenergy potential without causing competition for land required for other purposes, such as food production or nature conservation. Due to high net primary productivity, this presents an important opportunity for Indonesia to develop modern sustainable bioenergy while pursuing ambitious landscape restoration initiatives, such as its NDC target of restoring 14 million hectares of degraded land by 2030.

This book offers scholars, practitioners, small and medium enterprises and private sector actors interested in biomass energy and landscape restoration with insights from an interdisciplinary group of scientists who combined forces to integrate bioenergy and landscape restoration in Indonesia. The book covers a wide range of topics relating to bioenergy production and landscape restoration, including Indonesian government policies and initiatives in recent decades, geo-spatial assessments of degraded land available for bioenergy production, landowners' perceptions of bioenergy crops and landscape restoration, and specific information on promising bioenergy species such as *nyamplung*, bamboo and pongamia.

Table 1. Summary of the book's chapters and content

Chapter	Main topic	Research area	Methodology	Contributing manuscripts
2	Indonesian bioenergy policies, initiatives and research	Indonesia	Policy analysis	Widayati et al.
3	Potential degraded land for bioenergy production	Indonesia	Spatial analysis	Jaung et al.
4	Landowner perceptions and preferences for bioenergy production	Buntoi Village, Central Kalimantan	Survey questionnaire, interviews, focus group discussions	Artati et al.
5	Suitable tree species for bioenergy production under diverse conditions	The tropics	Narrative review	Shin et al.
6	Socioeconomic and environmental outcomes of agroforestry systems with bioenergy tree species	Wonogiri District, Central Java	Field research, focus group discussions	Rahman et al.
7	Suitability of bioenergy tree species on burned and degraded peatlands	Buntoi Village, Central Kalimantan	Field research	Maimunah et al.
8	Changes in soil biodiversity after peatland fires	Buntoi Village, Central Kalimantan	Field research	Shin et al.
9	Growth Performance of *Calophyllum inophyllum* on previously burned land	Bukit Soeharto Forest, East Kalimantan	Field research	Leksono et al.
10	Characteristics and benefits of bamboo as a potential bioenergy species	Indonesia	Literature review	Sharma et al.
11	Oil content of *Pongamia pinatta* seeds extracted using improved extraction methods	Ujung Kulon National Park, Banten	Field research	Hasnah et al.
12	Potential of *Calophyllum inophyllum* for green energy production and restoration of degraded lands	Gunung Kidul and Wonogiri Districts, Central Java	Field research	Leksono et al.
13	*Pongamia pinatta* as a possible option for degraded land restoration and bioenergy production	Indonesia	Review and synthesis	Leksono et al.
14	Lessons from the Mentawai biomass gasification power plant project	Mentawai Islands District, West Sumatra	Case study	Wahono et al.

1.2 Key contributions and findings

The book's chapters cover a broad range of topics: bioenergy policies, geospatial mapping and analysis of degraded lands and their suitability for bioenergy production, landowners' perceptions and preferences, the socioeconomic and environmental benefits of bioenergy plantations, and suitable bioenergy species for producing biomass and biodiesel (Table 1). Under the right conditions, and if managed appropriately, bioenergy species can be intercropped with food crops to create systems that simultaneously support energy security, food security and landscape restoration. Well-designed agroecosystems could produce bioenergy crops that contribute substantially to Indonesia's bioenergy targets, while minimizing unintended social and environmental effects and enhancing local livelihoods. The potential of bioenergy crops at the agroecosystem level is high, but questions remain over economies of scale for bioenergy production at the macro level, the availability of suitable lands, and operational and transaction costs. System designs need to ensure bioenergy production is sustainable and does not lead to further land and forest degradation. The chapters in this book answer these questions and build a comprehensive picture of using bioenergy crops for landscape restoration in Indonesia.

In Chapter 2, Widayati et al. investigate bioenergy initiatives and their applications for industries in Indonesia. Results indicate bioenergy studies progressing in the country, but knowledge being hard to access, and broader deployment remaining hard to achieve. Their research emphasizes the need for enabling conditions, including policies, financing and incentives, and for bioenergy provisioning in multifunctional land use or waste recycling systems.

In Chapter 3, Jaung et al. estimate the extent of degraded lands suitable for growing biodiesel and biomass species. Their research involved a spatial analysis to identity potentially suitable land, and two possible production, growth model and carbon stock scenarios: one involving five biomass and biodiesel producing species; and the other only biodiesel species. Study results reveal approximately 3.5 million ha of suitable degraded land with the potential to produce 1,105 PJ yr^{-1} of biomass and 3 PJ yr^{-1} of biodiesel under the first scenario and 10 PJ yr^{-1} of biodiesel under the second scenario.

In Chapter 4, Artati et al. apply Firth's logistic regression model to study landowners' perceptions of bioenergy tree species and their preferences for restoring degraded lands. Results show most landowners preferring familiar species with available markets, and few choosing the bioenergy species *Calophyllum inophyllum* L. due to the uncertainty of the bioenergy market. Their research recommends applying familiar bioenergy species, ensuring bioenergy markets for landowners, and providing extension support and capacity building.

In Chapter 5, Shin et al. identify bioenergy species suitable for different conditions. Results provide comprehensive information on bioenergy tree species, their ideal growing conditions (temperature, precipitation, pH etc.) and energy outputs, and provide insights for improved strategies for bioenergy production.

In Chapter 6, an article by Rahman et al. examines the social, economic and environmental benefits of *nyamplung* or *Calophyllum inophyllum*-based bioenergy production in different agroforestry systems combined with rice, maize, peanuts and honey. Through its calculations of crops' and different combinations of crops' net present values (NPV), the study's results show *nyamplung*-based agroforestry systems providing socioeconomic and environmental benefits on different scales.

In Chapter 7, Maimunah et al. explore, assess and compare the survival and growth performance of potential bioenergy crops in extreme environments (burned and degraded peatlands). Results demonstrate *nyamplung* and *kemiri sunan* species both performing better under agroforestry systems than as monocultures. Their research recommends growing these two species in agroforestry systems to maximize productivity in supporting livelihoods and sustainable development.

In Chapter 8, Shin et al. investigate and assess the soil macrofauna biodiversity and properties, and changes in soil fauna patterns in a burnt peatland area undergoing restoration with the establishment of a bioenergy plantation. Results show peatland fires causing hugely reduced numbers of soil mesofauna and microfauna individuals, and bioenergy tree survival rates and biodiversity being higher on unburnt than burnt peatland.

In Chapter 9, Leksono et al. report on the growth performance of *nyamplung* on previously burned land. Their findings indicate *nyamplung* trees showing robust adaptivity with a 90% survival rate on low fertility and acidic soils, and the trees enhancing soil properties and biodiversity by attracting birds and insects while providing a source of renewable energy. Surprisingly, they also show fertilizer applications and slope gradients having no significant effects on growth performance.

In Chapter 10, Sharma et al. discuss the benefits and characteristics of bamboo as a potential bioenergy species in Indonesia. The chapter describes bamboo in terms of availability, familiarity, livelihood potential and climate change, as well as the food-energy-environment trilemma. They show potential challenges in bamboo cultivation and management being displacement of native species, simplification of forest structure, and pollution from fertilizer use.

In Chapter 11, Hasnah et al. use a solvent extraction method to demonstrate the oil content of *Pongamia pinatta* seeds. Their results show pongamia producing more oil (27% to 45%) than bulk seed (15 to 19%). Findings also reveal that extraction methods, extraction machines and genetic factors can all influence pongamia oil production.

In Chapter 12, Leksono et al. explore the potential of *Calophyllum inophyllum* for green energy production and restoration of degraded lands in Indonesia. Their research shows the species being tolerant to and growing well in various environmental conditions, and concludes that with its high volume of non-edible oil, *Calophyllum inophyllum* is ideal for producing biodiesel, medicines, cosmetics and animal feed, and providing compost for soil enrichment. They show agroforestry systems growing the species on degraded land being socially, economically and environmentally favourable for local communities.

In Chapter 13, Leksono et al. provide a concise synthesis about how the nitrogen-fixing tree *Pongamia pinatta* is an ideal candidate for restoring degraded land while providing multiple economic benefits, including bioenergy. The study, which highlights the key benefits of pongamia in providing wood, fodder, medicine, fertilizer and biogas, suggests this multipurpose species holds great potential for helping Indonesia meet its energy demand while restoring much of its degraded land.

Finally, in Chapter 14, Wahono et al. investigate a biomass gasification power plant project in the Mentawai Archipelago to look at a potential development solution for the renewable energy industry. The chapter argues that local biomass production could provide the answer to the challenge of providing energy in rural areas. They propose a community- and biomass-based power generation system for rural electrification, which could result in affordable electricity, local economic growth and land restoration from biomass production.

1.3 Concluding comments and a way forward

For an energy-secure and low-carbon future, bioenergy is being promoted globally and in Indonesia as a feasible alternative to unsustainable fossil fuels for producing energy. Properly designed and well-managed systems for producing bioenergy on degraded lands can help Indonesia meet its energy targets, whilst facilitating a sustainable environment and improving local livelihoods. Research in various conditions and consideration of local communities are critical for sustainable bioenergy production and restoration of degraded lands and forests. Interdisciplinary strategies could make sustainable bioenergy production and ecosystem services possible. Careful planning is needed to ensure bioenergy crop development is environmentally friendly and does not compete for land with agricultural production, which could increase food insecurity and food commodity prices. In addition, system designs need to ensure bioenergy production is sustainable and does not lead to further land and forest degradation.

Over the past six years, CIFOR and partners have been conducting research to examine the potential benefits and challenges – from social, economic and environmental standpoints – of developing bioenergy crops on degraded lands in Indonesia. Hopefully, the studies included in this book can provide valuable contributions for consideration in decision making by investors, managers and policymakers.

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CHAPTER 2

Review of bioenergy initiatives in Indonesia for multiple benefits and sustainable development

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Abstract: Indonesia has committed to advancing its use of new and renewable energy (NRE) through its National Energy Policy (*Kebijakan Energi Nasional*). It has targeted NRE contributing 23% of the national energy mix by 2025, with bioenergy cited as one strategic measure for achieving this target. With Indonesia's abundant biomass resources, it is worth assessing and exploring potential bioenergy feedstocks, and identifying opportunities and challenges for development and upscaling. With sustainability being on global and national agendas, Indonesia is no exception with its focus on bioenergy. This chapter discusses bioenergy development initiatives in Indonesia over the past 15 years through a review of literature from 2005–2018, and provides a general review and updates to 2020. It discusses emerging issues pertinent to multiple-benefit potentials, competing uses and other development agendas. The study looks at Indonesia's abundant resources that could be developed for bioenergy, and discusses numerous studies dedicated to bioenergy development potential. Palm oil, *Jatropha curcas* and biogas are the most well-studied potential sources of bioenergy. Beyond these, implementation at scale remains a challenge, and feasibility studies including linkages with major offtakers are necessary. While many bioenergy initiatives have faced challenges with uptake, oil palm (*Elaeis guinensis*) biofuel is by far the most widely developed and used in Indonesia. Although opportunities exist to synergize bioenergy development with various development agendas, in some instances trade-offs might be necessary.

Keywords: Bioenergy, sustainable development, Indonesia, policy
Link: https://www.cifor.org/knowledge/publication/6617/
This is a revised version of an article previously published as an ICRAF Policy Brief (Widayati et al. 2017).

2.1 Introduction

Indonesia has committed to providing energy for its entire population through its National Energy Policy (*Kebijakan Energi Nasional*) as stipulated under Government Regulation No. 79/2014. The regulation specifies the importance of diversification, environmental sustainability and enhanced deployment of domestic energy resources. Diversified energy supply should include oil, coal, gas, and new and renewable energy (NRE). It mandates NRE contributing 23% of the national energy mix by 2025, where NRE can be derived from a range of sources, including geothermal, nuclear, micro-hydro, bioenergy, solar, wind, tidal and shale gas. Indonesia has also made commitments internationally to align energy provision with sustainability, as stated by the President of Indonesia at the Twenty-first Conference of Parties to the United Nations Framework Convention on Climate Change in 2015 (Ministry of Foreign Affairs 2019), and to further reduce net greenhouse gas emissions, as stipulated in its Nationally Determined Contribution (NDC) (Republic of Indonesia 2016).

Bioenergy is an important alternative renewable energy. It is defined as energy produced from plant biomass and plant-derived residues and waste (Souza et al. 2015). Traditional bioenergy mostly refers to energy from biomass burning, while modern bioenergy applies to energy produced through a wide range of technologies, including liquid biofuels, biorefineries, biogas and wood pellet heating systems (IRENA 2020). In Indonesia, forms of bioenergy being researched and developed include biodiesel, bioethanol, bio-aviation turbine fuel (bioavtur), bio-pellets, bio-briquettes, bio-oil, biogas and syngas (Bappenas 2015; Putrasari et al. 2016). Since 2006, initiatives developed by the Government of Indonesia (GoI) to meet national bioenergy policies and mandates include biofuel or *Bahan Bakar Nabati* (BBN) development, energy self-sufficient villages or *Desa Mandiri Energi* (DME), the Indonesia Domestic Biogas Programme (IDBP) or *Biogas Rumah* (BIRU), bioenergy power plants, the Sumba Iconic Island renewables project, and bioenergy plantations or *Hutan Tanaman Energi* (HTE). In 2016, bioenergy ranked first as an NRE in Indonesian in terms of installed capacity and utilization, followed by hydro, geothermal, mini and micro-hydro power, and solar, wind and wave power (DEN 2016).

Bioenergy is highly dependent on biological feedstocks, the most prominent of which are agriculture biomass, forestry biomass, animal manures and micro-algae. Another feedstock for bioenergy is derived from municipal waste (FAO 2004). According to the Technology Assessment and Application Agency (BPPT 2017), Indonesia has biomass energy resource potential of around 32,654 megawatts (MW) and an installed capacity of 1,626 MW. Bioenergy utilization, especially biofuel, biogas and biomass, is expected to rise (Abdurrahman 2018; Ministry of Environment and Forestry 2018). For instance, biofuel utilization was projected to rise from 6.4 million kilolitres (kl) in 2018 to 52.3 million kl by 2050. In addition, bioenergy-based heat and liquid fuels are planned to provide more than half of all renewable energy used in Indonesia by 2030 (IRENA 2017).

Bioenergy research plays a major role in providing foundations before wider uptake and implementation. It is essential to align bioenergy research and development initiatives. Studies show that for successful bioenergy development it is vital to consider the integration of upstream and downstream factors, such as bioenergy feedstocks and related industries, as well as bioenergy research and development. Recent studies have assessed the sustainability of bioenergy in Indonesia (Kemper and Partzsch 2018; Papilo et al. 2018). However, studies that take stock of the development of bioenergy initiatives are very limited, and lack information on the types of bioenergy and their geographical distribution (Widodo et al. 2006; Wirawan and Tambunan 2006; Legowo et al. 2007; Silviati 2008; Widodo and Rahmarestia 2008; Dharmawan et al. 2018).

2.2 Scope of the chapter

The chapter aims to highlight progress in bioenergy research and development initiatives in Indonesia, including their geographical distribution, and to review enabling factors and challenges for wider uptake and implementation. Further, the chapter also aims to derive lessons from relations in bioenergy development and ascertain their contextual relevance, multiple-benefit potentials and alignment with development and sustainability agendas.

This chapter builds on a policy brief entitled “Exploring the potential of bioenergy in Indonesia for multiple benefits” (Widayati et al. 2017), which was based on the “International workshop on developing science- and evidence-based policy and practice of bioenergy in Indonesia within the context of sustainable development” held in 2017. The workshop aimed to increase awareness of the current state of bioenergy research and development; identify gaps, bottlenecks and challenges in developing bioenergy value chains and uptake; and provide input and recommendations for creating enabling conditions to address challenges. Adopting the four main sections in the policy brief, this chapter provides a review of the significant body of literature published from 2005–2018, and follows up with a general review and discussion of relevant updates to 2020. Ultimately, the chapter discusses emerging issues surrounding bioenergy feedstocks, especially in agriculture, forestry and bioenergy development, in relation to multiple-benefit potentials, competing uses and other development agendas.

2.3 Review of bioenergy research and development initiatives

GoI has developed several bioenergy programmes since 2006. These include biofuel (BBN) development along with a national biofuel taskforce, BIRU domestic biogas installation, biogas-based power generation, improved cook stoves, the Sumba Iconic Island renewable energy project, bioenergy plantations, candlenut biodiesel development, and bio-avtur development (Ministry of Energy and Mineral Resources 2014). Bioenergy research has been conducted to support the development of sustainable, viable and affordable bioenergy initiatives in Indonesia. Many studies have investigated prospective feedstocks for bioenergy in different regions of Indonesia, but these have yet to be applied to bioenergy initiatives involving state-owned enterprises as offtakers.

2.3.1 Bioenergy research

Numerous studies have investigated potential feedstocks for bioenergy development in Indonesia. These encompass agriculture feedstock, forestry feedstock, non-wood forest feedstock and other biomass (Annex 1). Roughly, 80 forms of feedstock were researched in Indonesia during 2005–2018. These feedstocks included biodiesel, bioethanol, bio-oil, biogas, bio-pellets, charcoal briquettes and syngas. Most research studies focused on agriculture feedstock, the highest number being on oil palm, followed by paddy, sugarcane, coconut, cassava, maize, sorghum and other agro-lignocellulose sources. The Agriculture Research and Development Agency under the Ministry of Agriculture has been conducting research into developing biodiesel from crude palm oil (CPO) since 1992 (Puslitbang Pertanian 2006). Besides its abundance, oil palm bioenergy provides greater energy potential than other feedstocks with its stable production and adequate infrastructure.

Studies on forestry feedstocks have mainly focused on lignocellulose sources and oil-containing seeds. Several studies from 2005 to 2018 looked at the bioenergy potential of non-timber forest products (NTFPs) such as nipa palm (*Nypa fruticans*), sago (*Metroxylon sagu*), black sugar palm (*Arenga pinnata*) and bamboos (Bambuseae). Other resources, mostly researched since 2007, are animal manure, microalgae, municipal solid waste (MSW) and waste cooking oil (WCO). Since the issuance of Presidential Regulation No. 5/2006 on National Energy Policy and its update under Government Regulation No. 79/2014, several government agencies have made progress towards the policies' bioenergy goals. The Ministry of Agriculture, for example, has promoted studies on the bioenergy potential of biomass from oil palm, maize, cassava, sugar, jatropha, candlenut and animal manure (Agustian 2015). In addition, the Forestry and Environmental Research, Development and Innovation Agency (FOERDIA) under the Ministry of Environment and Forestry (MoEF) developed an initiative to derive bioethanol from black sugar palm in Boalemo District in Gorontalo Province, which was incorporated into the energy self-sufficient villages (DME) programme.

Although most oil palm biomass related studies have looked at the potential of palm oil for biodiesel, some studies looked at potential for bio-pellets, bioethanol, biogas, syngas and bio-oil, with palm oil mill effluent (POME) being processed to produce biogas for electricity, and lignocellulose residues of oil palm being broken down chemically to produce bioethanol, bio-oil and bio-pellets. The Indonesian Institute of Sciences (LIPI), for instance, succeeded in converting 1,000 kg of oil palm empty fruit bunches (EFBs) into 150 litres of 99.95% fuel grade ethanol. Funding for research into using oil palm for bioenergy has increased since the creation of the CPO Fund in 2015, with the fund supporting oil palm research and development. In 2016, the CPO Fund allocated IDR 10.68 trillion for oil palm-related research, a 22-fold increase over 2015 (IDR 476 billion). After oil palm, the second most dominant agricultural biomass being assessed for bioenergy was paddy, the most common use being electric power generation through the conversion of syngas and heat into electricity from gasification, thermal incineration or microbial fuel cell (MFC) technologies. In addition, rice straw and rice husk bio-pellets have been investigated as potential sources of biomass for electricity generation.

Studies in the forestry sector have looked at lignocellulose from woody biomass for species such as calliandra (*Calliandra calothyrsus*), acacia (*Acacia sp.*) and albizia (*Paracerianthes falcataria*), mostly for manufacturing bio-pellets, generating electricity, power and heat. Meanwhile, studies on oil-bearing fruits and seeds from jatropha (*Jatropha curcas*), Alexandrian laurel or *nyamplung* (*Calophyllum inophyllum* L.), candlenut (*Reutealis trisperma*), Indian beech (*Pongamia pinnata*) and sea mango (*Cerbera odollam*) were also common. After successful studies by the Bandung Institute of Technology from 2005–2007, for instance, jatropha biodiesel has been used widely in the DME programme. In addition, NTFP biomass has also been researched. Nipa palm, black sugar palm and palmyra palm (*Borassus flabellifer*) sap have been studied for bioethanol production through fermentation processes (Effendi 2010; Fahrizal et al. 2013; Hidayat 2015; Imron et al. 2015). These plants have all been identified as having bioethanol production potential (FORDA 2013).

Other sources of biomass that have been studied extensively are municipal solid waste (MSW), waste cooking oil (WCO), animal manure and microalgae. MSW was explored for generating electricity, whereas animal manure was studied for its biogas potential. Both WCO and microalgae were reported to produce biodiesel after processing with chemical treatments (Hidayat 2008; Hadiyanto et al. 2012; Kartika and Widyaningsih 2012; Setiawati and Edwar 2012; Pradana et al. 2017). LIPI has looked at the potential of microalgae, such as *Nannochloropsis* sp., *Chlorella* sp. and *Scenedesmus* sp., expecting them to provide a ten-fold increase in total biodiesel productivity per hectare over CPO biodiesel (LIPI 2015). Major sources studied for hydrocarbon syngas were paddy, oil palm, coconut, woody biomass, rubber and municipal waste.

Looking at the geographical distribution of bioenergy feedstock research and development, most research into biodiesel has been conducted in Java, Sumatra, Kalimantan, Sulawesi, Papua, Maluku, Nusa Tenggara and Bali (Figure 1). These regions have the potential to become biodiesel producers due to their feedstock availability. They have also been locations of research into bioethanol. Riau, Lampung and Jambi provinces have been the most favoured sites for research into bio-oil derived from oil palm, paddy, woody biomass and MSW, primarily due to the availability of feedstocks in those areas.

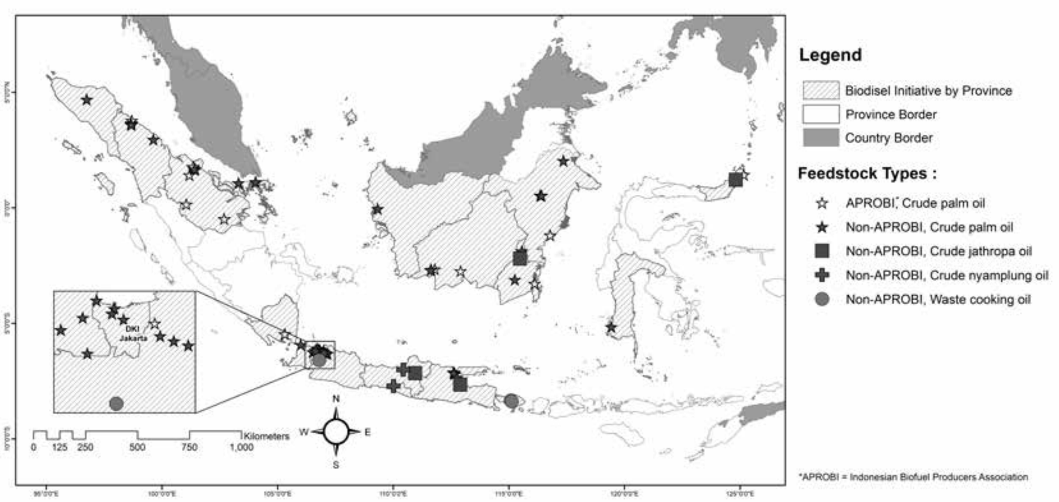

Figure 1. Geographical distribution of biodiesel initiatives in Indonesia

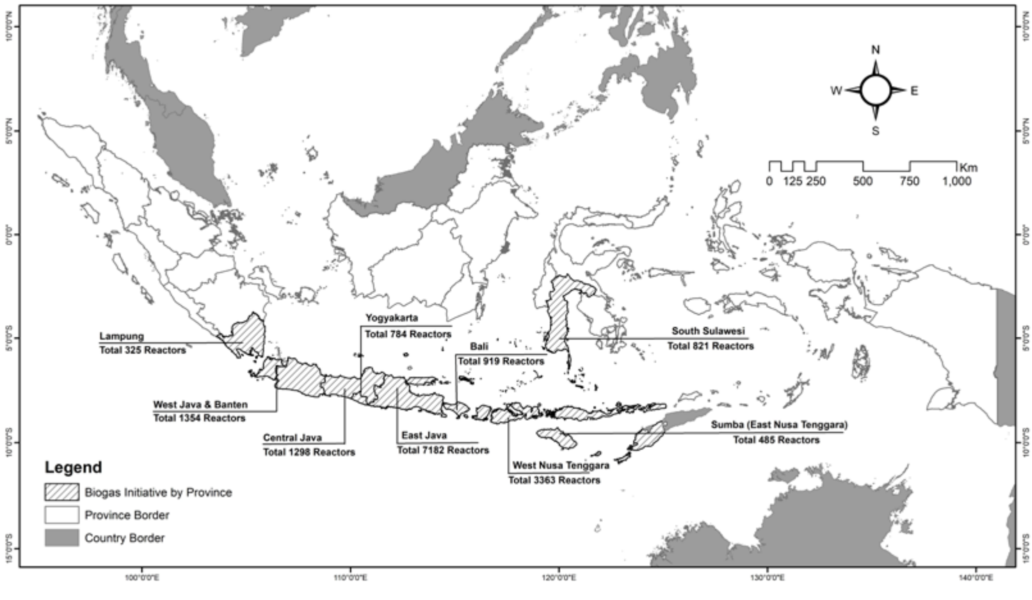

Figure 2. Geographical distribution of biogas initiatives in Indonesia

Key research locations for biogas and syngas have been Java, Sulawesi, some provinces in Sumatra and Kalimantan, Papua, Maluku, Bali and Nusa Tenggara (Figure 2). Java has been the main island for initiatives on producing biogas from animal manure. Research on bio-briquettes and bio-pellets has also been based mostly on Java, and to a lower extent Sumatra, Kalimantan and Sulawesi. As studies into bio-briquettes and bio-pellets have looked mainly at their production from oil palm residues, coconut waste, wood waste, calliandra (*Calliandra* *calothyrsus*) and acacia (*Acacia* sp.) biomass, those islands were able provide the necessary feedstocks. Studies in Papua have looked at the abundance of biomass for bioenergy feedstocks, but no studies there have focused on the region's potential for bio-briquettes, as most have looked at bio-pellets for electricity generation, bioethanol or biodiesel.

For Papua in particular, research has focused on biomass and oil-bearing fruits for more advanced bioenergy products, such as wood pellets, and on direct electricity generation, bioethanol and biodiesel. Following on from these studies, state-owned electricity company PT PLN has built biomass power plants in Papua and West Papua provinces (IESR 2019).

2.3.2 Bioenergy development initiatives

Beyond research, bioenergy development initiatives have been established in various parts of Indonesia. These initiatives are categorized here by bioenergy type, i.e., biodiesel, bioethanol, biogas, syngas, charcoal briquette or bio-pellet, with an additional category being integrated bioenergy initiatives under the energy self-sufficient villages or *Desa Mandiri Energi* (DME) programme.

Biodiesel

Biodiesel initiatives have been developed from four feedstock types: crude palm oil (CPO), crude jatropha oil (CJO), crude *nyamplung* oil (CNO) and waste cooking oil (WCO). These initiatives are predominantly situated in Java, with some in Sumatra, Kalimantan, Sulawesi and Bali (see Figure 1). CPO is the most used feedstock for biodiesel initiatives in Java, Sumatra and Kalimantan, because of its abundance. Indonesia has a large number of CPO biodiesel companies, but only 25 were members of the Indonesian Biofuel Producers Association (APROBI) in 2018. The geographical distribution of companies involved in all four biodiesel feedstock types is shown in Figure 1.

CJO biodiesel initiatives have been developed in Java, Kalimantan and Sulawesi, though these initiatives have encountered issues with feedstock viability and sustainability. Java, Kalimantan and Sulawesi are highly suitable locations for the development of CPO biodiesel initiatives because of GoI's commitment to executing the DME programme. CNO biodiesel initiatives have only been developed on Java, mainly in Central Java Province, because the feedstock (*nyamplung*) is widely cultivated and grows well in the region. WCO biodiesel initiatives have been established and supported by local governments in Bogor and Bali. In Bogor, two companies (PT Mekanika Elektrika Egra and PT Bumi Energi Equatorial) are collaborating with the Bogor Municipal Government to use WCO biodiesel for its 'Trans Pakuan' city buses. A similar collaboration is ongoing in Bali, where the company PT Bali Hijau Biodiesel and the Bali Provincial Government are collaborating to develop 'Ucodiesel' from used cooking oil to fuel four Bali Green School buses. However, both initiatives risk being discontinued due to various issues including material supply continuity and profit-oriented goals (Fujita et al. 2015; Syahdan et al. 2017).

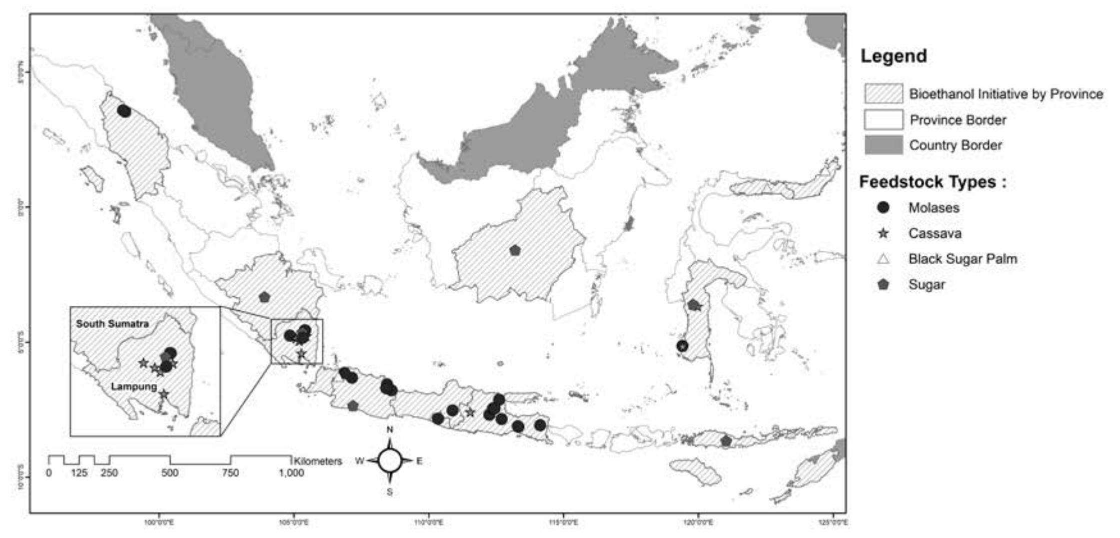

Figure 3. Geographical distribution of bioethanol development initiatives in Indonesia

Bioethanol

Bioethanol is the second most important biofuel after biodiesel in supporting the BBN biofuel programme. Four feedstocks are used for bioethanol initiatives: cassava, molasses, sugar and black sugar palm (Figure 3). Of the 40 bioethanol production initiatives realized to date, 32 use molasses and sugar, seven use cassava, and one utilizes black sugar palm. Only one initiative, which uses molasses as its feedstock, is registered with APROBI. Most companies produce bioethanol for cosmetics, pharmaceuticals, cigarettes, ink and paint. Most of these initiatives are centred in Lampung and East Java, as these provinces are the main feedstock producers, though black sugar palm has been utilized for ethanol production outside these provinces in Gorontalo, Tangerang and Minahasa. The sugar palm-based bioenergy initiative in Gorontalo involves MoEF, while the one in Tangerang involved the Technology Assessment and Application Agency (BPPT) before it was forced to stop due to unprofitable implementation and negative perceptions associated with ethanol production and alcohol. Bioethanol is also being produced from similar feedstock using traditional methods in South Minahasa, though the resulting bioethanol concentration is low at only 24% (Wenur and Waromi 2017). Consequently, the process necessitates re-distillation and improved processing.

Biogas

Biogas initiatives were implemented in Indonesia in 2007 to support the DME programme, while the Indonesia Domestic Biogas Programme (IDBP) or *Biogas Rumah* (BIRU) spearheaded by the Rumah Energi Foundation has been ongoing since 2012. This programme, with more than 25,000 biogas units in 14 provinces, has benefited more than 100,000 people (Rumah

Energi 2021), with biogas commonly used for cooking and electricity generation. The BIRU programme is widely distributed throughout Java, but is only being implemented in a few areas in Sumatra, Kalimantan and Sulawesi (Figure 2). Papua has abundant feedstock for biogas, including animal manure and Sago, the residues of which can be digested anaerobically to produce biogas (Muthukumar and Sangeetha 2014). However, biogas initiatives have been absent in the region.

Bio-pellets and bio-briquettes

As Indonesian bio-pellet initiatives generally utilize wood as their raw material, the resulting bio-pellets are often referred to as wood pellets. Such initiatives are mostly situated in Java, and to a lesser extent in Kalimantan and Sumatra (Figure 4). Wood pellet initiatives have been boosted through government support with the establishment of 31 ‘HTE’ biomass plantations (Ministry of Environment and Forestry 2018). State-owned forestry company Perhutani is collaborating with the Korea Forest Service (KFS) and Korea Green Promotion Agency (KGPA) to accelerate biomass plantation and wood pellet development. Around 3,300 trees have been cultivated in the Bogor Forest Management Unit (FMU), with cultivation extended to the planting of a 500-ha *gamal* (*Gliricedia sepium*) forest in the Semarang FMU. Other fast-growing trees, such as calliandra (*Calliandra calothyrsus*), albizia (*Paraserianthes falcataria*) and acacia (*Acacia* sp.), are also being cultivated. A community forest-based wood pellet project, called ‘Hutan Rakyat untuk Green Madura’, was established in Bangkalan District, Madura, with the tagline *“Kaliandra Bersemi, Pelet Kayu Berseri”*, implying that growing calliandra will ensure successful wood pellet production. This co-enterprise aims to support a low-carbon economy and climate change mitigation.

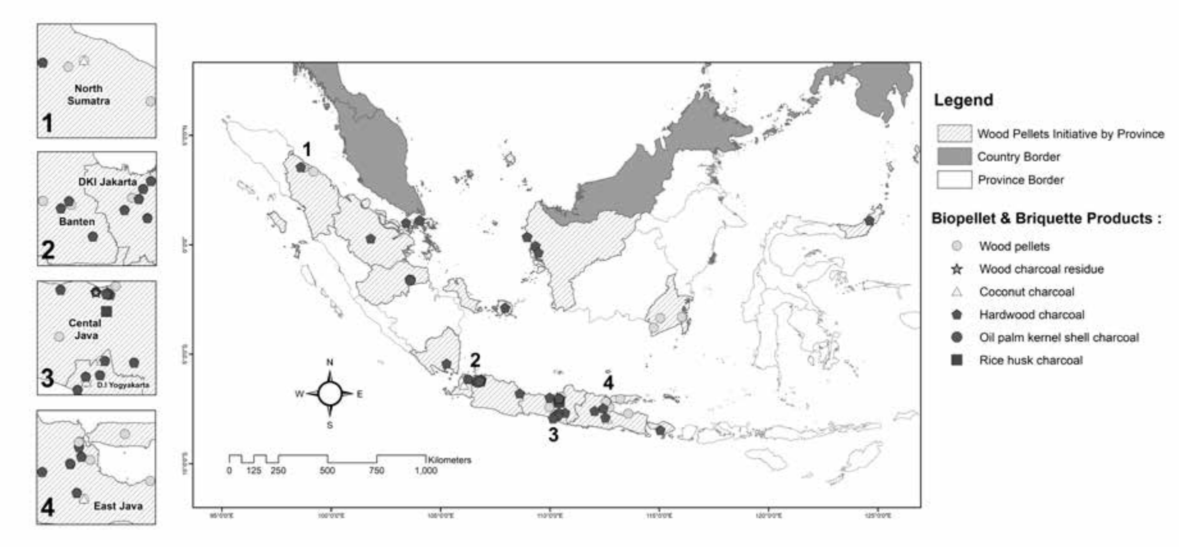

Figure 4. Distribution of bio-pellet and charcoal briquette development initiatives in Indonesia

In addition to wood pellets, charcoal briquette bioenergy initiatives have also been developed with different types of feedstock, including coconut, hardwoods, oil palm kernel shells, rice husks and wood residues. Most charcoal briquette initiatives are based in Java where woody biomass is widely available. Indonesian charcoal briquettes have international markets, particularly Taiwan, and compete well with briquettes produced in Malaysia, Thailand and Vietnam.

Bioenergy power plants

Biogas, bio-pellets and syngas have all been used to produce energy, heat or electricity. Figure 5 shows bioenergy power plants that have been in operation in Indonesia since 2001. Feedstocks for bioenergy power plants include oil palm residues, POME, MSW, wood residues, maize cobs and bamboo. These initiatives fall under two types of contracts: excess power and independent power producers. The first bioenergy power plant, built in Riau Province in 2001, runs on oil palm residue and POME feedstocks. Oil palm residues are thermally incinerated to produce synthetic hydrocarbon gases or heat for electricity generation (Pradana and Budiman 2015). POME is converted to electricity by means of biogas (Firdaus et al. 2017). Oil palm residues and POME are utilized in bioenergy power plants developed in Riau, North Sumatra, Bangka Belitung and Jambi provinces where oil palm residues are ubiquitous.

An MSW-based power plant has been built in Surabaya, while plans to build similar plants in Semarang, Bekasi and cities in South Sumatra and Bali provinces are awaiting approval. MSW-based power plant development plans are ongoing in Makassar, Surakarta, Bandung,

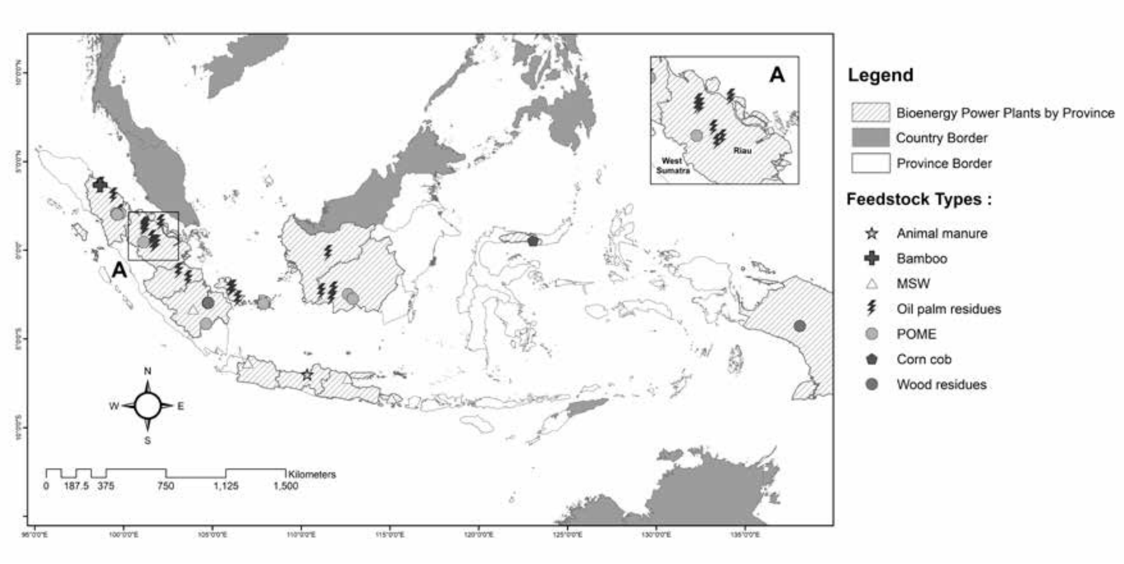

Figure 5. Bioenergy initiatives for biomass-based electricity generation in Indonesia

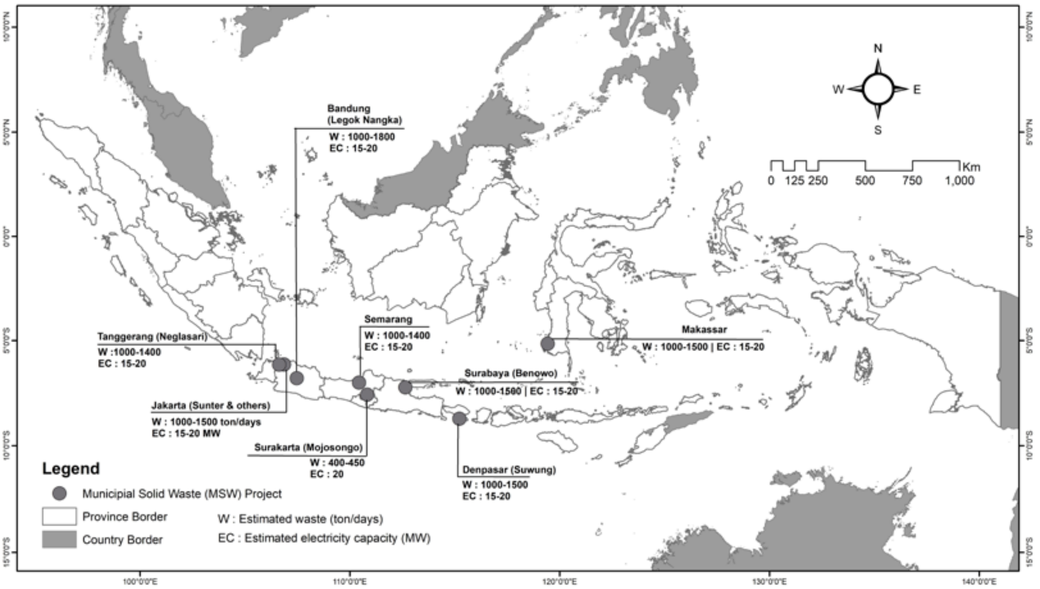

Figure 6. Operational and planned MSW-based power plants in Indonesia

Tangerang and Jakarta (Figure 6), with projections of 400–800 tons of waste per day being converted to electricity, and power capacities ranging from 9.96 to 20 MW. Surakarta is one of the cities pioneering the realization of waste-based power plants in Indonesia (Ishaan 2018). Other feedstocks being harnessed for power generation are animal manure, maize cobs, wood and bamboo, and these are the feedstocks for power plants in Semarang, Gorontalo, South Sumatra and Papua, and Mentawai Islands, respectively.

The energy self-sufficient villages or Desa Mandiri Energi (DME) programme

DME is a GoI bioenergy initiative aimed at addressing increasing fossil fuel prices and energy crises. The purposes of the programme are village energy self-sufficiency, and to create jobs, reduce poverty and encourage targeted villages to plan productive enterprises (Taufiq and Purwoko 2013). According to Widodo et al. (2008), five key commodities in the DME programme are jatropha, palm oil, coconut, cassava and sugarcane. In addition, bioenergy from maize, sorghum and black sugar palm can also be developed through DME. The programme is managed directly by the Ministry of Development of Disadvantaged Regions, Ministry of Agriculture, Ministry of Home Affairs, Ministry of Manpower and Transmigration, Ministry of Marine and Fisheries and state-owned agroindustry company PT RNI. Figure 7 shows 27 provinces implementing DME. There are two types of DME: non-fuel DME (micro and macro hydropower, biogas and solar) and biofuel DME (jatropha, *nyamplung* and palm oil). Unfortunately, despite being a nationwide initiative, the programme has encountered several issues during implementation, particularly for jatropha where there have been problems with securing jatropha seedlings, encouraging farmers to grow jatropha, cultivating it and making it profitable.

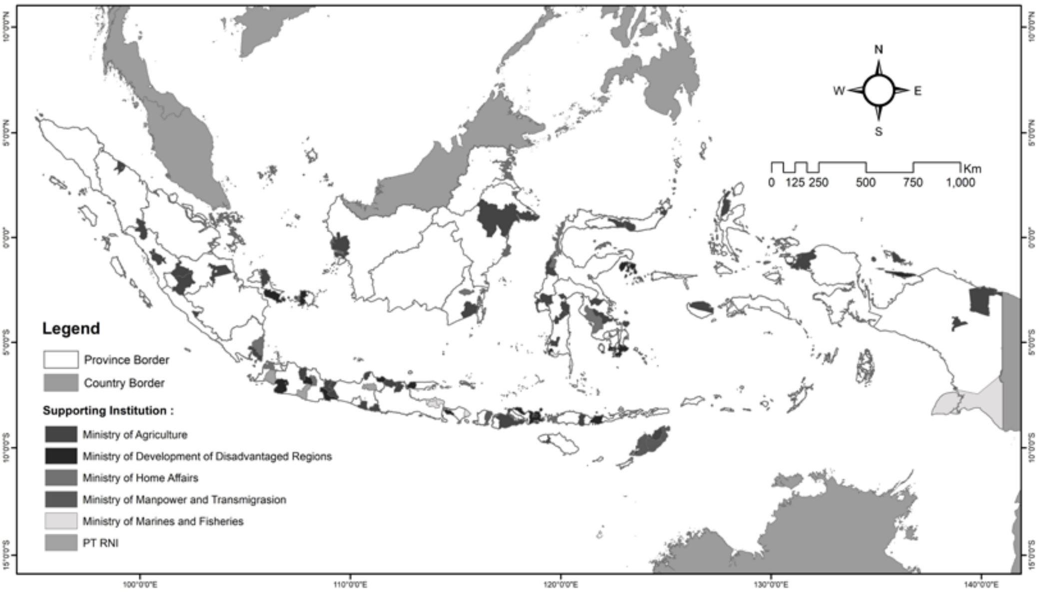

Figure 7. Energy self-sufficient villages (DME) programme sites in Indonesia

2.4 Enabling conditions and challenges for bioenergy initiatives

2.4.1 Enabling policies

Bioenergy development in Indonesia has been enabled by a range of national policies and regulations (See details in Annex 2). Under Law No. 30/2007 on Energy, GoI emphasizes regional and central government roles in enhancing the nation's NRE stock and its utilization. In addition, this law mandated the development of a National Energy Policy (*Kebijakan Energi Nasional*), which was finally formulated and stipulated under Government Regulation No. 79/2014. An important element of the National Energy Policy is the promotion of NRE. Under the regulation, GoI is committed to providing facilities and incentives to stakeholders who conserve energy and develop alternative energy sources, such as geothermal, biofuel, hydro, solar, wind, biomass, biogas, wave power, and ocean thermal energy conversion. The regulation was elaborated on with Presidential Regulation No. 22/2017 on the National Energy Plan, which mandates NRE contributing 23% of the national energy mix by 2025 and 31% by 2050. In pursuing these policies, the Ministry of Energy and Mineral Resources issued Ministerial Regulation No. 10/2012 on the realization of NRE in different sectors, including transportation and electricity generation. Electricity generation is mainly managed by the Ministry of Energy and Mineral Resources and operated by state-owned electricity provider PT PLN. Through Minister of Energy and Mineral Resources Regulation No. 50/2017, GoI obliges PLN to purchase electricity from new and renewable energy sources. However, as mandatory purchases are subject to the National Energy Policy and General Plan for Electricity (RUKN), this regulation is not always enforceable.

2.4.2 Incentives for bioenergy development

Beyond policies, other enabling conditions are required for bioenergy application. One such enabler is ‘incentives’, which broadly cover government provision of subsidies, infrastructure and tax breaks. Another aspect of incentives is the provision of mutual benefits to the various parties interacting in the production, provision and use of bioenergy. Mutual benefits, such as rewards for ecosystem services or through public-people-private partnerships and other interactions between government, the private sector and communities, can serve as indirect incentives. Such incentives are addressed in Ministry of Finance Regulation No. 21/2010 and Government Regulation No. 9/2016 amending Government Regulation No. 18/2015. In addition, it is clear that Presidential Regulation No. 5/ 2006 on the National Energy Policy, which promotes the use of new renewable energy, provides facilities and incentives to stakeholders who conserve energy and develop alternative energy sources, such as biomass and biogas. Furthermore, Law No. 30/2007 on Energy also stipulates that GoI may offer facilities and/or capital, tax, or fiscal incentives for renewable energy development until renewables become economically viable. The government also plays an important role in guaranteeing feedstock supply.

2.4.3 Major challenges to bioenergy development

Two major challenges commonly associated with bioenergy development have been identified. First is the high initial investment costs for production chains. These high costs are mostly associated with biomass delivery (transportation) and establishing processing facilities. The latter is of greater concern due to issues relating to land acquisition and social conflicts. Potential investors are confronted with poor incentives provided by existing regulations, political situations, lack of familiarity with energy efficiency projects, high financial and technical risks, and poor financial returns. In addition, upfront transaction costs for energy audits and feasibility studies have discouraged investors, who are also concerned that costs might increase due to a lack of experience among engineering service companies. Taking these concerns on board, GoI has established a more attractive investment mechanism for renewable energy power plants under Minister of Energy and Mineral Resources Regulation No. 4/2020, which amends regulations No. 50/2017 and No. 53/2018.

Second, despite some progress being made with B30 biodiesel (a 30:70 blend of biodiesel and petroleum diesel by volume), major hurdles to overcome for effective B30 implementation include biodiesel quality, stakeholder support, pricing policy, trade barriers and protectionism. Furthermore, adoption of the B40 blend, originally projected for June

2021, has been delayed due to the high price of crude palm oil. Other sources of biodiesel have never got beyond the pilot stage for similar reasons. The failure of jatropha (*Jatropha curcas*) biodiesel in 2005–2007 was mainly due to the absence of supporting factors for implementation. WCO biodiesel initiatives established with local government support in Bogor and Bali to fuel buses have failed due to raw material supply issues and their profit-oriented goals. Concomitant with the above, a specific challenge for small-scale producers is a general lack of access to biodiesel production chains.

2.4.4 Obstacles for upscaling/wider application

Many studies have been undertaken at downstream and upstream levels to support bioenergy implementation. Despite providing sufficient evidence to support implementation, these studies have yet to be fully utilized. Meanwhile, progress with large-scale use of bioenergy for fuel and power generation has been varied. With pilot projects across Indonesia, issues surrounding off-take by state-owned enterprises have been cited as major challenges. For instance, state-owned oil and gas company Pertamina has committed to applying second generation biofuels through an integrated project approach in partnership with plantation and processing licensors. This commitment is reflected in its mission to 'carry out integrated core business in oil, gas, new and renewable energy based on strong commercial principles' (https://pertamina.com/en/vision-mision-and-the-6c-excellent-values). Pertamina has also conducted first-stage field trials for co-processing with Refinery Unit (RU) II Dumai to produce green diesel and with RU III Plaju to produce green gasoline. In addition, Pertamina and the Bandung Institute of Technology have developed a catalyst for green processing (PIDO 130) to process refined bleached deodorized palm oil. However, issues identified for biofuel development (Trikoranto 2018) in Pertamina included: 1) limited supply of fatty acid methyl esters (FAME) for blending B20 (a 20:80 blend of biodiesel and petroleum diesel) in Pertamina fuel terminals; 2) technical issues related to B20 usage in cars; 3) infrastructure readiness for blending non-PSO B20; and 4) difficulties accelerating B30 and B40 implementation. Indonesia has been making strides with B30 implementation and is planning to move towards B40 in 2022.

Other challenges to scaling up bioenergy initiatives in Indonesia are distances and provision of infrastructure between sites of power generation and the main electricity grid, as well as prices for bioenergy electricity, which typically need to be higher than prices paid by state-owned electricity company PLN. Uncertain feedstock availability and unattractive prices are also factors hampering the use of biomass for larger-scale electricity production.

2.5 Contextual relevance in bioenergy initiatives

Other pertinent aspects beyond the core areas of bioenergy development are relevant issues to learn from. Contextual relevance and locality factors are important considerations. These include connections between the supply side, such as feedstock availability, and the demand side, such as the population's energy needs. Though in many instances, bioenergy initiatives in Indonesia have considered these aspects, their successes and continuity have varied.

2.5.1 Geographic and local contexts

Priority areas for bioenergy development should be based on local needs, while also taking resource or feedstock availability into account. A common reference for local need is the electrification ratio. PLN has faced major challenges in areas where no main energy grid systems exist. However, this should not stop electricity generation with PLN as the main offtaker, considering that energy provision can be harmonized with bioenergy through different strategies. For example, priority could be given to areas where PLN is using diesel generators. Similarly, in areas where energy supply from Pertamina is limited, strategies could be developed for integration with biodiesel and bioethanol, which may benefit from the contextual relevance of feedstock availability.

Competitiveness with fuel and power generated from fossil fuels is another consideration in developing alternative energy sources, including bioenergy. In areas where electricity is very expensive and fossil fuel prices very high, which is typically the case with the outer islands in Indonesia, bioenergy production is locally relevant and economically viable. Conversely, where fossil fuel prices are low, bioenergy may not be able to compete under normal market conditions.

2.5.2 Successes and challenges based on contextual factors

Various bioenergy initiatives have been developed with strong locality or geographical contexts, especially relating to feedstock availability. While locality factors determine cost efficiency for things such as transport, they also relate to other factors such as land suitability and climate for specific crops. In some areas, feedstocks such as nipa palm (*Nypa fruticans*) and sago (*Metroxylon sago*) grow wild along coastal riverbanks, while in other areas feedstocks are cultivated as an integral part of initiatives to ensure supply for energy production. As discussed earlier, various initiatives, such as the case of crude jatropha oil, have faced challenges despite efforts to ensure local feedstock provision. The case of black sugar palm-based bioethanol also demonstrated feedstock availability issues, although cultural issues were present as well. Such issues resulted in these initiatives either failing or being discontinued.

With Indonesia's extensive oil palm plantation development, palm oil-based biofuel can flourish and is being mainstreamed under incremental biofuel blending targets. Palm oil-based biofuel has been Indonesia's main consideration in responding to its falling fossil fuel production and in efforts to reduce fossil fuel imports (Dharmawan et al. 2018). It also benefits from the massive development of industrial oil palm plantations for CPO production in many parts of Indonesia. Low fossil fuel prices and established infrastructure for fossil fuel-based energy provision are competing factors, as mentioned earlier. However, CPO-based biofuel is flourishing, even in regions like Java with good fossil fuel supply, due to strong supporting policies and other enabling factors such as developing vehicle infrastructure favouring biofuel uptake.

2.6 Multiple uses and alignment with development agendas

Other environmental and development agendas can provide foundations for synergies with bioenergy development so that bioenergy can provide added value as a bi-product or co-benefit. Bioenergy crops can be planted for multiple purposes in addition to energy production. Selecting species that can be harvested sustainably and are suitable as bioenergy feedstock for the restoration of degraded or marginal lands could provide income, fuel and energy for local communities. Feedstock from crop waste, such as rice husks and rice straw, can also have multiple uses as bioenergy sources.

2.6.1 Restoration of degraded land

Through Minister of Environment and Forestry Decree No. 306/2018, GoI identified 14 million ha of degraded lands requiring restoration and rehabilitation. Indonesia also has large areas of degraded peatlands. In 2016, GoI targeted 2 million ha for peatland restoration and established the Peatland Restoration Agency (BRG) to manage the process. Minister of Environment Decree No. 163/2009 and the Peatland Restoration Agency's national strategy document (BRG 2016) recommend bioenergy crop species, which are listed in the Ministry of Environment and Forestry's technical guidance for restoration and rehabilitation. Jaung et al. (2018) identified 3.5 million ha of degraded lands in Indonesia with high potential for bioenergy crop cultivation. However, due to their spatial distribution, economic viability remains the biggest challenge.

Various initiatives have proposed and conducted trials on potential bioenergy crops for degraded land rehabilitation. One plant with potential for biomass-based power generation is bamboo, which is also beneficial for rehabilitation and stabilization of steep gradients and riverbanks. Bamboo is considered promising due to its abundance, energy potential and environmental and livelihood benefits. Nevertheless, various challenges, including economic viability, have been identified and require further study (Sharma et al. 2018).

Nyamplung (*Calophyllum inophyllum)* is a widely recognized bioenergy crop, the seeds of which produce oil with potential for biofuel. The species is listed in various documents, including from MoEF and the Peatland and Mangrove Restoration Agency (BRGM), as a potential species for degraded land restoration. Trials in different degraded land settings have demonstrated that *nyamplung* can survive harsh conditions in severely degraded peatlands as well as on mineral soils (Maimunah et al. 2018; Leksono et al. 2021). In addition to degraded peatland restoration, *nyamplung* has also been named as a potential species for mining area reclamation, with an initiative in Central Kalimantan (Maimunah, pers.com.).

2.6.2 Social and community forestry

The integration of community management rights in the forestry sector in Indonesia has led to social forestry schemes, such as *Hutan Kemasyarakatan* (community forest) or *Hutan Tanaman Rakyat* (community plantation forest). The community-based practices under these schemes have the potential to become sources of biomass for bioenergy feedstock. In addition, the agroforestry systems integrating trees and various crops common in many social forestry schemes in Indonesia may offer options for combining feedstocks and other commodities within a single system. Wood extracted from forests can be used to produce wood pellets or bio-briquettes, while lignocellulose/polysaccharide-based forest biomass and seed oils can be used for producing bioethanol, biodiesel, bio-oil and syngas. Smallholder farmers could play pivotal roles as feedstock providers, and beyond feedstock provision, they could be empowered to establish farmer organizations or platforms to become actively involved in bioenergy value chains. Any efforts to make this happen should include the development of business models for small and medium enterprises (SMEs) and other forms of local capacity building. Through such synergies, social or community forestry could become viable schemes for smallholders to connect with buyers and achieve economies of scale.

2.6.3 Multiple benefits or competing uses?

The integration of bioenergy crops with other tree species under agroforestry practices has the potential to provide multiple benefits for local livelihoods and food security. Honey production in *nyamplung* agroforestry systems can provide livelihood benefits that help local food security (Rahman et al. 2019). ‘Agrosilvofishery’ systems combining *nyamplung* cultivation with fish farming are a viable option for peatland environments, and have potential to provide livelihood sources while restoring degraded peatlands (Samsudin et al. 2020). Such integrated systems also reduce pressure on arable land and natural forests.

Nyamplung oil has been shown to have other economic benefits, such as in the production of therapeutic oils (Léguillier et al. 2015). As the crop already has market value in Indonesia due its popularity in essential oil products, it has further potential to provide benefits when incorporated with degraded land restoration initiatives. Such multiple benefits could pose a problem with competition if bioenergy production were also on the agenda. However, even in such cases, bioenergy could still be produced from residues and processed for bioethanol.

As described earlier, rice straw has significant potential for use as a feedstock for biogas. No additional investment or additional land would be required to produce this feedstock, there would be no competition with food crops, and the utilization of such waste could provide multi-functionality within a landscape. However, there is a competing use for rice straw or rice husks as fertilizer for agriculture. These competing uses may prove beneficial for local livelihoods and/or local economies, but may also pose a supply continuity risk if bioenergy production is to be developed. This demonstrates a trade-off between bioenergy production and soil fertility management with rice straw being an organic nutrient source.

2.6.4 Sustainability of palm oil biofuel programmes

Oil palm-based biofuel has been the most widely developed bioenergy in Indonesia. Its development was initiated with the aim of reducing dependence on fossil fuel imports, and as part of the renewable energy mandate under Indonesia's National Energy Policy. Progressive development is shown in the form of an incremental increase in biofuel blends, currently at B30. Challenges to achieving targets remain for various reasons. These include falling global oil prices and the recent economic recession due to the pandemic (da Conceição et al. 2021). Questions remain over whether oil palm biofuel truly represents an environmentally and climate friendly energy source, with concerns that oil palm plantation expansion risks further forest loss (da Conceição et al. 2021; Halimatussaidah et al. 2021). This concern is exacerbated by the current rate of oil palm productivity (da Conceição et al. 2021), as biofuel production may be dependent on incentives (Halimatussaidah et al. 2021). The social aspects of oil palm biofuel are still problematic, considering the opportunity gaps between large-scale companies and smallholders when participating in biofuel programmes. With such challenges, further implementation will require strong policies and regulations to ensure alignment with environmental and social safeguards and compliance with green and no-deforestation principles. Efforts to strengthen smallholder involvement can be developed by ensuring their participation in bioenergy value chains. For instance, smallholder farmers could engage in the provision of biomass-based feedstocks, and participate with simple and affordable technologies in the production of certain forms of bioenergy such as wood pellets, carbon charcoal and bio-briquettes.

2.7 Summary of successes, gaps and challenges

Bioenergy initiatives in Indonesia have shown some achievements and successes over the course of the past ten to fifteen years. The Government of Indonesia has established clear policies targeting renewable energy as part of the national energy mix. The government's support for NRE has shown goodwill towards more sustainable energy sources, including bioenergy. To date, bioenergy research and development in Indonesia has been achieved with a collaborative nature across research and development agencies/organizations.

Oil palm-based biodiesel is being used at the national level, with some being exported to Europe. The B30 blend has one of the highest biofuel contents in the world, and as such can be considered quite an achievement for GoI. Abundant feedstock and established infrastructure are important factors in this success. The use of biogas at small-scale and household levels in rural areas has also been promising, and is especially beneficial for optimizing waste for biomass.

Nevertheless, gaps, bottlenecks and challenges remain for bioenergy to play a bigger role in Indonesia in contributing to NRE implementation and application at scale beyond the pilot stage.

Reviews and discussions in this chapter are summarized below:

- Bioenergy research has made significant advances in recent decades, but implementation and wider uptake remain major challenges, with the exception of some progress in palm oil biofuel and biogas programmes.
- Bioenergy production costs are high, particularly in the initial or investment stages; and economic viability is a challenge. Government financial support and incentives are necessary for implementation at scale.
- There is criticism with CPO-based biofuel, that small-scale producers lack access to participate in biodiesel production. This will require policy and regulatory improvements and interventions, as well as capacity strengthening on business enterprises.
- Despite the current abundance of feedstocks, the quality, quantity and continuity of different tree-crop species might pose risks for large-scale bioenergy production. Competition may emerge over the use of feedstocks due to other more profitable or preferable utilizations. Land use-related aspects of feedstocks may also be problematic, with risks of land conversion for more profitable commodities and tenurial issues in many parts of the country.

2.8 Conclusions and ways forward

Bioenergy has huge potential for development in Indonesia. It is linked to forestry, agriculture and urban waste management. In order to realize existing potential, enabling conditions (policies and regulations governing incentives, price guarantees and subsidies) need to be created together with associated governance structures at different levels of administration. Research findings should be applied to pilots and wider implementation. Research and development organizations need to engage with the private sector, state-based offtakers and other practitioners to develop innovations and business models at appropriate scales and in the most suitable contexts. For example, the latter may refer to particular geographical areas that are economically and socially attractive for bioenergy development and in need of land rehabilitation. Importantly, future research should consider PLN and Pertamina's power and fuel requirements in research areas in order to improve viability. Finally, bioenergy development should be planned in the context of sustainability, green-growth planning, climate-change mitigation and adaptation, degraded land restoration and achievement of Sustainable Development Goals. Strategic mapping is required to synergize existing efforts, on restoration or REDD+ for instance, and to ensure synergy with programmes and schemes on the ground. Bioenergy development in Indonesia has the potential to contribute to the Bonn Challenge, a global effort to restore 350 million hectares of degraded and deforested lands by 2030, and to the nation's Nationally Determined Contribution and greenhouse gas emissions reduction commitments under the United Nations Framework Convention on Climate Change.

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Annexes

Annex 1. Bioenergy feedstocks and numbers of studies on their potential in Indonesia

	Bioenergy Feedstock	Period of research/study							
		≤ 2004	2005–2006	2007–2008	2009–2010	2011–2012	2013–2014	2015–2016	2017–2018
	Agriculture feedstock								
1	Oil palm (*Elaeis guinensis*)		3	7	10	15	13	34	37
2	Coconut (*Cocos nucifera*)		2	3	2	4	8	8	10
3	Sugarcane (*Saccharum officinarum*)		1	7	3	3	6	8	13
4	Cassava (*Manihot esculenta*)		1	7	4	5	8	7	2
5	Paddy (*Oryza sativa*)			4	3	7	12	9	14
6	Maize (*Zea mays*)		5	3		2	4	4	7
7	Sorghum (*Sorghum bicolor*)			2	2	5	1	1	4
8	Rapeseed (*Brassica napus*)						1		
9	Cacao (*Theobroma cacao*)							2	2
10	Tobacco (*Nicotiana* sp.)								1
11	Banana (*Musa* sp.)								1
12	Pineapple (*Ananas comosus*)				1	1	2		1
13	Peanut (*Arachis hypogaea*)						1	1	
14	Soybean (*Glycine max*)		1				1	1	1
15	Sunflower (*Helianthus annuus*)						1		
16	Sweet potato (*Ipomoea batatas*)		1	2	1	1		1	2
17	Taro (*Colocasia esculenta*)				1	2	1	3	
18	Ganyong (*Canna edulis*)			1	1	1	2		
19	Agricultural biomass (lignocellulose)	1	1	1		2	5	1	7

	Bioenergy Feedstock	Period of research/study							
		≤ 2004	2005–2006	2007–2008	2009–2010	2011–2012	2013–2014	2015–2016	2017–2018
	Forestry feedstock								
20	Wood biomass (lignocellulose)	3		3	1	4	13	5	18
21	Calliandra (*Calliandra calothyrsus*)		2			1	2	1	4
22	Acacia (*Acacia* sp.)				1	1	2	2	7
23	Eucalyptus (*Eucalyptus* sp.)							1	1
24	Lead (*Leucaena leucocephala*)					1		1	1
25	Albizia (*Paraserianthes falcataria*)				1	1	2	3	1
26	Bishop wood (*Bischofia javanica*)							1	
27	Tarap (*Artocarpus odoratissimus*)						1		
28	Corkwood (*Sesbania grandiflora*)						1		
29	Gmelina (*Gmelina arborea*)					1		1	1
30	Durian (*Durio zibethinus*)								1
31	Gamal (*Gliricedia sepium*)						1		2
32	Jatropha (*Jatropha curcas*)		9	4	4	3	6	4	3
33	Mahang (*Macaranga gigantea*)							1	
34	Mara (*Macaranga tanarius*)							1	
35	Candlenut (*Aleurites trisperma*)				1	4		4	3
36	Alexandrian laurel (*Calophyllum inophyllum*)				2	3	11	4	12
37	Indian beech (*Pongamia pinnata*)					1	2	1	4
38	Rubber (*Hevea brasiliensis*)	1		1		2	4	2	4
39	Cashew (*Anacardium occidentale*)							1	
40	Mangrove cannonball (*Xylocarpus moluccensis*)						1		
41	Pine (*Pinus merkusii*)					1			1

	Bioenergy Feedstock	Period of research/study							
		≤ 2004	2005–2006	2007–2008	2009–2010	2011–2012	2013–2014	2015–2016	2017–2018
42	Jabon (*Anthocephalus cadamba*)								2
43	Trembesi (*Samanea saman*)								1
44	Kapok (*Ceiba pentandra*)				1		1	1	2
45	Pulai (*Alstonia scholaris*)							1	
46	Pride of India (*Lagerstroemia speciose*)							1	
47	Wild mango (*Spodias pinnata*)						1		
48	Iron (*Eusideroxylon zwageri*)								2
49	Cloves (*Syzygium aromaticum*)								1
50	Mahogany (*Swietenia* sp.)						1		1
51	Teak (*Tectona grandis*)			1		1		2	1
52	Meranti (*Shorea uliginosa*)						1		
53	Red meranti (*Shorea leprosula*)							2	
54	Breadfruit (*Artocarpus altilis*)						1	1	
55	Bendo (*Artocarpus elasticus*)							1	
56	Cinnamon (*Cinnamomun zeylanicum*)							1	
57	Coffee (*Coffea* sp.)							1	1
58	Evergreen magnolia (*Michelia velutina*)						1		
59	Cananga (*Cananga odorata*)							1	
60	Laban (*Vitex* sp.)							1	1
61	Jackfruit (*Artocarpus heterophyllus*)								1
62	Loba (*Symplocos fasciculata*)								1
63	Cajeput (*Melaleuca* sp.)								3
64	Amboyna pine (*Agathis alba*)						1		
65	Sea mango (*Cerbera manghas*)					2	1	1	1

	Bioenergy Feedstock	Period of research/study							
		≤ 2004	2005–2006	2007–2008	2009–2010	2011–2012	2013–2014	2015–2016	2017–2018
66	Africa leaf (*Vernonia amygdalina)*								1
67	Spiked pepper (*Piper aduncum*)								1
68	Butterfly (*Bauhinia purpurea*)								1
69	Indian rhododendron (*Melastoma malabthricum*)								1
	Non-Wood Forest Feedstock								
70	Nipa palm (*Nypa fruticans*)				1	3	6	8	3
71	Black sugar palm (*Arenga pinnata*)			1	1	3	2	5	4
72	Sago (*Metroxylon sago*)		1	2	4	3	3	4	3
73	Palmyra palm (*Borassus flabellifer*)					1		2	
74	Bamboo (*Dendrocalamus* sp.)							1	4
75	Hyacinth (*Eichhornia crassipes*)						1	3	1
76	Elephant grass (*Pennisetum purpureum*)								1
	Other biomass								
77	Municipal waste			1	1		4	3	5
78	Waste cooking oil			1	2	3	1	3	4
79	Animal manure			1	5	7	10	12	6
80	Microalgae			2	2	5	3	1	3
81	Human excreta							1	

Source: from various sources analysed by the authors

Annex 2. Policies, regulations, national plans and other strategic documents associated with bioenergy development in Indonesia

No.	Type and Institution	Subject	Objectives and details	Feedstock	Bioenergy type
1	Government Regulation No. 3/2005	Supply of Electricity	Regulates partnerships between independent power producers (IPPs) and state electricity company PLN to develop electricity projects. An exception is given to companies that generate power for their own use or those using renewable energy; this way they can set up plants independently without having to partner with PLN	Various	Various
2	Ministry of Energy and Mineral Resources Blueprint for the National Energy Implementation Program 2005–2025 issued	National Energy Implementation Programme	Provides development road maps for various sectors, covering renewable and non-renewable energy sectors	Various	Various
3	Presidential Regulation No. 5/2006	National Energy Policy	Promotes the use of renewable energy by providing facilities and energy conservation incentives to operators and developers of certain alternative energy sources like geothermal, biofuel, river flow, solar, wind, biomass, biogas, sea waves, and ocean thermal energy	Various	Various
4	Presidential Instruction No. 1/2006	Biofuel Supply and Utilization	Mandates 13 ministries and governmental agencies to take action in advancing biofuel development from feedstock supplies	Agriculture	Biofuel
5	Presidential Decree No. 10/2006	The establishment of a National Biofuel Development Taskforce	The taskforce was formed to formulate a roadmap for biofuel development in Indonesia, and ended in 2008	Not specified	Biofuel
6	Law No. 30/2007	Energy	Emphasize the contributions of local and national governments in order to enhance the nation's stock of new and renewable energy and its utilization	Various	Various
7	Government Regulation No. 6/2007	Forest arrangement, forest management plan, and forest utilization	Utilization of non-timber forest products in unproductive production forests based on sustainable principles	Forest	Biomass

No.	Type and Institution	Subject	Objectives and details	Feedstock	Bioenergy type
8	Law No. 18/2008	Waste management	Aimed at improving public health and environmental quality, and utilizing waste as a resource.	Municipal waste	Biomass
9	Government Regulation No. 3/2008	Forest governance, management and utilization	Ensuring the term "*utilization of non-timber forest products in unproductive production forest*" includes the development of biofuel feedstock commodities	Forest	Biomass
10	Minister of Energy and Mineral Resources Regulation No. 32/2008	Biofuel utilization	Stipulates minimum biodiesel and bioethanol quantities to be utilized in public and non-public transport, commercial and industry sectors, and for electricity generation with a progressive scale to 2025	Not specified	Biodiesel and bioethanol
11	Minister of Finance Regulation No. 156/2009	GoI bears biofuel VAT for 2009 budget	Reduce climate change impacts; ensure renewables make up 23% of national energy mix by 2025 and 31% by 2050	Not specified	Biodiesel and Bioethanol
12	Law No. 30/2010	Electricity Law	Gives higher priority for renewable energy and clean technology in electricity generation and encourages small-scale distributed power generation from renewable sources such as biomass	Forest and agriculture	Biomass-based power generation
13	Minister of Energy and Mineral Resources Regulation No. 39/2017	Approaches for implementing new and renewable energy	Provides guidance for new and renewable energy implementation and power saving	Various	Biomass, biogas, municipal waste, biofuel
14	Minister of Energy and Mineral Resources Regulation No. 19/2013	Purchasing of electricity by PLN from municipal waste power plants	Stipulates permits, prices and technical requirements for implementation. In its general provisions, the regulation recognizes municipal waste power plants for generating power using solid waste through sanitary landfill or zero-waste technologies	Municipal waste	Biomass
15	Minister of Energy and Mineral Resources Regulation No. 25/2013	Biofuel utilization	Revises some articles on sanctions for business units failing to meet biodiesel allocation targets, and includes intra-sectoral responsibilities (oil and gas, electricity, renewable resources) in achieving targets	Not specified	Biodiesel and bioethanol
16	Minister of Energy and Mineral Resources Regulation No. 4/2012	Feed-in tariffs for biomass-based electricity	Sets feed-in tariffs for electricity generated from biomass	Forest and agriculture	Biomass-based electricity

No.	Type and Institution	Subject	Objectives and details	Feedstock	Bioenergy type
17	Government Regulation No. 79/2014	National Energy Policy (KEN)	Independent energy management; energy availability; equal energy access; jobs; environment	Various	Various
18	National Medium-Term Development Plan (RPJMN) 2015–2019	The National Medium Term Development Plan for 2015–2019	Declared the need to improve the contribution of solid waste-based electricity. The plan stipulates that local governments should ensure the provision of locations and embed this vision into municipal planning.	Various	Various
19	Minister of Energy and Mineral Resources Regulation No. 27/2014	PLN to buy electricity from biogas and biomass electricity generators with capacities up to 10 MW	FiTs or feed-in tariffs are formulated as follows: base tariff X regional factor. Base tariffs range from IDR 1,050 to IDR 1,500 per kWh when connected to low voltage supplies	Not specified	Biogas and biomass
20	Ministry of Energy and Mineral Resources Strategic Plan 2015-2019	Five-year strategic planning	Established three mechanisms for biogas development: non-commercial biogas programmes through the state budget (public investment); semi-commercial biogas programmes through Indonesia-Netherlands cooperation; and commercial biogas programmes through private investment in biogas power plants. Stipulates that in order to support national energy diversification, dedicated land should be prepared for biofuel crops	Various	Various
21	Ministry of Agriculture Strategic Plan 2015–2016	Five-year strategic planning	Encouraged the provision of energy feedstock to help achieve the target of 23% renewable energy (including biofuel) in the national energy mix by 2025	Agriculture	Not specified
22	Minister of Energy and Mineral Resources Regulation No. 20/2014	Biofuel supply, utilization and trading system	Obliges all sectors to use 30% biofuel blend by 2025. Set a 5% higher target to achieve by April 2015	Not specified	Biodiesel and Bioethanol
23	Government Regulation No. 24/2015	Oil Palm Plantation Fund	Plantation development, human resources capacity building, downstream improvements for plantations, optimization of utilization for industry, bioenergy and exports, price stability, increased welfare	Palm oil	Biofuel

No.	Type and Institution	Subject	Objectives and details	Feedstock	Bioenergy type
24	Presidential Regulation No. 61/2015	CPO Fund	To ensure sustainable oil palm plantation development by using the fund for human resources development in the palm oil sector, research and development, palm oil promotion, and oil palm plantation revitalization, including biodiesel utilization (as an add-on)	Palm oil	Biofuel
25	Minister of Energy and Mineral Resources Decree No. 3239/2015	Biofuel Market Price Index	Reduce fossil fuel imports; generate foreign exchange	Not specified	Biofuel
26	Minister of Energy and Mineral Resources Regulation No. 26/2015	Biodiesel utilization through CPO Fund	Expedite biodiesel blending mandate targets; ensure a well distributed biodiesel fund	Palm oil	Biofuel
27	Minister of Energy and Mineral Resources Regulation No. 44/2015	Purchase of electricity by PLN from municipal waste power plants	Refines definition of municipal waste power plants, stating that they work by a) methane gas collection in sanitary landfills or anaerobic digestion, and b) thermally from thermochemical technology. The pricing policy in the new regulation differs from the previous one	Municipal waste	Biomass
28	Minister of Environment and Forestry Regulation No. 12/2015, as amended by Minister of Environment and Forestry Regulation No. 17/2017	Plantation forest (HTI) establishment	Defines types of woody forest plants, cultivated annual crops, and other types of plants that support forest product industries, and supply raw materials for wood biomass- and biofuel-based bioenergy	Forest	Biomass
29	Government Regulation No. 105/2015	Utilization of forest estate	Non-forestry uses of forest estate are allowed for strategic objectives, such as certain forms of agriculture for food and energy security	Forest	Not specified
31	Minister of Energy and Mineral Resources Regulation No. 12/2015	Provision, utilization and trading administration for alternative biofuels	To achieve the 30% renewables targets by 2025 for sectors including transportation, electricity generation, industry and commercial activities		
32	Minister of Industry Regulation No. 31/2015	Ministry of Industry Strategic Plan 2010–2014		Not specified	Not specified

No.	Type and Institution	Subject	Objectives and details	Feedstock	Bioenergy type
33	Presidential Regulation No. 18/2016	Acceleration of the development of municipal waste power plants in seven cities in Indonesia	Infrastructure funded through state and regional government budgets. Article 7 of the regulation states that PLN is obliged to purchase power generated from plants in Jakarta, Tangerang, Bandung, Semarang, Surakarta, Surabaya and Makassar	Municipal waste	Biomass
34	Minister of Energy and Mineral Resources Regulation No. 21/2016	PLN to buy electricity from biogas and biomass electricity generators with capacities up to 10 MW	Promotes higher rates than the previous regulation. USD cents are used as the currency reference	Not specified	Biogas and biomass
35	Presidential Regulation No. 24/2016	Collection and utilization of (oil palm) Plantation Fund	Oil Palm Plantation Fund Management Agency (BPDPKS) is responsible for collecting, managing and distributing CPO funds	Palm oil	Biofuel
36	Minister of Finance Regulation No. 30/2016	Service fees for public service agencies for Palm Oil Plantation Fund management at the Ministry of Finance	Revenues collected through levies, which are different to palm oil export tax, charged on exports of crude palm oil and derivatives, and vary from USD 20 to 50 USD per MT	Not specified	Not specified
37	Minister of Finance Regulation No. 140/2016	Determination of export goods subject to export duties and tariffs for export duties	Export tax ranges from 0 USD per MT when the international CPO price is below USD 750, to USD 262 per MT when the international CPO price is USD 1,250	Palm oil	Not specified
38	Presidential Regulation No. 22/2017	RUEN (National Energy Plan)	Renewable energy to make up 23% of the national energy mix by 2025 and 31% by 2050 as long as economic needs are met	Various	Various
39	Minister of Energy and Mineral Resources Decree No. 1415/2017	(RUPTL) National Electricity Generation Plan	Meeting energy demand with required standards and lowest cost. Reducing fossil fuel use and increasing use of renewable energy, especially hydro and geothermal	Various	Various
40	Minister of Energy and Mineral Resources Regulation No. 12/2017	Utilization of renewable energy resources for electricity	National energy security, CO_2 emissions reductions	Various	Various
41	Minister of Energy and Mineral Resources Regulation No. 50/2017	Amended with Minister of Energy and Mineral Resources Regulations No. 53/2018 and 4/2020	The government obliges PLN to purchase power from plants with renewable energy sources. PLN is compelled to operate renewables-based power plants with 10 MW must run capacity	Various	Various

No.	Type and Institution	Subject	Objectives and details	Feedstock	Bioenergy type
42	Minister of Energy and Mineral Resources Regulation No. 12/2017	Utilization of renewable energy resources for electricity	Promotes national energy security and decreases CO_2 emissions through the utilization of solar power, wind, water, biomass, biogas, solid waste, and geothermal power plants	Various	Various
43	Minister of Energy and Mineral Resources Regulation No. 53/2018	Amended with Minister of Energy and Mineral Resources Regulation No. 4/2020	No changes to renewables prices and build, own, operate and transfer (BOOT) scheme. Biofuel is added as renewable energy to generate electricity	Various	Various
44	Minister of Energy and Mineral Resources Regulation No. 4/2020	Utilization of renewable energy sources for electricity supply	(i) The renewed possibility for PLN to use the direct appointment mechanism, (ii) the removal of the requirement that projects be developed exclusively under the BOOT scheme, and (iii) the fact that PLN must prioritize the purchase of electricity from renewables IPPs (based on the must-run regime) without any restrictions on generation capacity	Various	Various
45	Minister of Energy and Mineral Resources Regulation No. 16/2020	Ministry of Energy and Mineral Resources Strategic Plan for 2020–2024	Updated plan for bioenergy development in Indonesia	Various	Various

CHAPTER 3

Mapping degraded lands in Indonesia for bioenergy production potential

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Abstract: This study conducted a spatial analysis in Indonesia to estimate degraded lands potentially suitable for growing biodiesel species (*Calophyllum inophyllum, Pongamia pinnata* and *Reutealis trisperma*) and biomass species (*Calliandra calothyrsus* and *Gliricidia sepium*). Degraded lands have limited functions for food production, carbon storage, and conservation of biodiversity and native vegetation. Thus, identifying their potential to produce bioenergy can contribute to sustainable development by helping society to meet increasing energy demands and secure a new renewable energy source. The identified potential degraded lands were further examined with two scenarios: 1) an all-five-species scenario, examining the growth of all five species, and 2) a biodiesel-species-only scenario, analysing the growth of only biodiesel species. Study results illustrated approximately 3.5 million ha of degraded lands potentially suitable for these species in Indonesia. The all-five-species scenario indicated that these lands had the potential to produce 1,105 PJ yr^{-1} of biomass and 3 PJ yr^{-1} of biodiesel. The biodiesel-species-only scenario illustrated that these lands had the potential to produce 10 PJ yr^{-1} of biodiesel. In addition, many of these degraded lands were limited to support economies of scale for biofuel production due to their small land sizes. The study findings contribute to identifying lands with limited functions, modelling the growth of biofuel species on regional lands, and estimating carbon stocks of restored degraded lands in Indonesia.

Keywords: degraded land, biodiesel, biomass, energy, Indonesia
Link: https://www.cifor.org/knowledge/publication/7086/
This is an edited version of an article previously published in *Sustainability* (Jaung et al. 2019).

3.1 Introduction

Bioenergy production from degraded lands might help society meet increasing energy demands and secure a new source of renewable energy for its sustainability. These potential benefits have attracted global attention to the feasibility of using degraded lands to produce bioenergy (Lewis and Kelly 2014). In Indonesia, for example, energy demand is growing rapidly due to its urbanization, economic growth and population increase (IRENA 2017). For these reasons, the Government of Indonesia set ambitious targets in 2015 to increase its biodiesel and bioethanol consumption to 30% and 20%, respectively, of total energy consumption by 2025 (Presidential Regulation No. 12/2015) (GAIN, 2017). Current biofuel production in Indonesia, however, is far from meeting these targets. In 2016, biofuel production was only 0.05% (or 3.66 billion litres) of the total fuel consumption for the year (or 70 billion litres) (GAIN 2017). According to the Indonesian National Energy Council (DEN 2017), moreover, its average energy demand would increase by around 4.9% per year from 2015 to 2025. This surge in expected demand has increased interest in the feasibility of using degraded lands to provide a new source of renewable energy in Indonesia (ICCC 2014; Wulandari et al. 2014; Baral and Lee 2016; Borchard et al. 2017).

In order to realize these potential benefits, however, bioenergy production must be sustainable in various ways. The expansion of biofuel production can result in reduced food production, which is particularly the case for palm oil. Indonesia is the largest palm oil producer and exporter in the world, and palm oil is a major feedstock for the production of liquid biofuels in the country (Harahap et al. 2017). In addition, the expansion of biofuel production through conversion of rainforests and peatlands would release large amounts of carbon from both aboveground and belowground reservoirs and create a biofuel carbon debt (Fargione et al. 2008; Goh et al. 2017). Such expansion could also threaten – or destroy – rich biodiversity and native ecosystems in these lands (Danielsen et al. 2009). Thus, for renewable energy to be sustainable, biofuel production from degraded lands should avoid compromising food production, carbon stocks, biodiversity and native vegetation. In many studies on degraded lands, however, data on the availability of such lands and their feasibility to deliver sustainable biofuel cannot be compared directly due to the diverging definitions of degraded lands used (Lewis and Kelly 2014) and because of the many potential biofuel species available in Indonesia (ICCC 2014; Wulandari et al. 2014; Baral and Lee 2016; Borchard et al. 2017).

To reduce this knowledge gap, this study (1) assesses degraded lands that have limited functions to produce food, to sequestrate carbon stocks on land, and to maintain vegetation and biodiversity, by adopting the definition of degraded lands from the Indonesia Climate Change Center (ICCC) (ICCC 2014); and (2) examines the suitability of the degraded lands to grow key species for biodiesel production (*Calophyllum inophyllum*, *Pongamia pinnata* and *Reutealis trisperma*) and biomass production (*Calliandra calothyrsus* and *Gliricidia sepium*). Indeed, biofuel production from degraded lands needs to overcome various obstacles as well, including improving the capacity of refineries, building business models for landowners and refineries, securing the property rights of the land, resolving potential conflicts among stakeholders, encouraging smallholder participation, competing with low-price fuels, and mitigating potential invasion by biofuel species (Bryan et al. 2008; Richardson and Blanchard 2011; ICCC 2014; Maraseni and Cockfield 2015; Baral and Lee 2016; Borchard et al. 2017). However, investigation of these challenges first requires an understanding of the degraded lands available for biofuel production and potential biofuel species. Thus, this study analyses these lands and species and estimates their potential energy production.

3.2 Potential biofuel species in Indonesia

While many energy crops exist in Indonesia, here we assessed five tree species with the potential for biodiesel production (i.e., *C. inophyllum*, *P. pinnata* and *R. trisperma*) or biomass production (i.e., *C. calothyrsus* and *G. sepium*) on degraded lands (Scott et al. 2008; Ong et al. 2011; Syamsuwida et al. 2014; Fadhlullah et al. 2015; Leksono et al. 2015; Hambali et al. 2016; Borchard et al. 2017). These species are native to Indonesia and tolerant to lands with harsh conditions that are normally unsuitable for agriculture; thus, these species have the capacity to not compete with food production (Table 1). The study intentionally excluded bamboo and other non-woody species as it mainly focuses on tree species for bioenergy production. Oil palm was excluded due to its large potential to compromise food production.

Table 1. Potential biofuel species in Indonesia

Species	Indonesian name	Tolerable condition	Local use	Biomass type	Food consumption
C. calothyrsus [a]	*Kaliandra*	Drought Acidic soil Sandy soil	Firewood and animal feedstock	Wood	No
C. inophyllum [b]	*Nyamplung*	Salinity Sandy soil	Wood, medicine, and cosmetics	Seed oil	No
G. sepium [c]	*Gamal*	Acidic soil	Firewood, animal feedstock and medicine	Wood or seed oil	No
P. pinnata [d]	*Malapari*	Salinity Water logging Drought	Wood, firewood and medicine	Seed oil	No
R. trisperma [e]	*Kemiri sunan*	Sloping land	Pesticide and fertilizer	Seed oil	No

a Adaganti et al. 2014; Amirta et al. 2016; Fadhlullah et al. 2015; Orwa et al. 2009; Palmer et al. 1994

b Bustomi et al. 2008; Chandra et al. 2013; Leksono et al. 2014, 2015; Ong et al. 2011

c Amirta et al. 2016; Atabani et al. 2013; Bhattacharya et al. 2003; Dahlanuddin et al. 2014; Knothe et al. 2015

d Al Muqarrabun et al. 2013; Aminah et al. 2017; Aunillah and Pranowo 2012; Hendra 2014; Scott et al. 2008; Syamsuwida et al. 2015

e Fuwape and Akindele 1997; Herman et al. 2013; Orwa et al. 2009; Riayatsyah et al. 2017

C. calothyrsus is a fast-growing shrub of 5–6 m height (Orwa et al. 2009). In Indonesia, it is called “kaliandra” and is used for firewood and land restoration due to its fast growth and good adaptability to a wide range of habitats (Syamsuwida et al. 2014; Amirta et al. 2016). The shrub is also used for animal feed (Palmer et al. 1994; Wulandari et al. 2015). It grows in various soil types, including sandy clays and acid soil (Adaganti et al. 2014; Herdiawan and Sutedi 2015). There is emerging interest in biofuel production from *C. calothyrsus* since it is highly cellulosic (46–48%), fast-growing, suitable for a short rotation and adaptable to diverse habitats (Fanish and Priya 2013; Adaganti et al. 2014; Syamsuwida et al. 2014; Yaliwal et al. 2014; Amirta et al. 2016).

C. inophyllum is a medium-to-large tree of 8–20 m height (Ong et al. 2011). Called “nyamplung” in Indonesia, the tree is used for its wood (e.g., building canoes) and seed oil (medicines and cosmetics) (Bustomi et al. 2008; Ong et al. 2011). The oil is slightly toxic for human consumption (Ong et al. 2011). As it tolerates windy and sandy conditions, its major habitats include coastal areas, but it also grows inland at high elevations (Bustomi et al. 2008; Ong et al. 2011). Several studies have analysed biofuel production from *C. inophyllum* oil because this species can yield up to 20 metric tons of inedible oil per hectare (Bustomi et al. 2008; Ong et al. 2011; Chandra et al. 2013; Leksono et al. 2014, 2015; Fadhlullah et al. 2015).

G. sepium is a medium-sized species of 2–15 m height (Orwa et al. 2009). In Indonesia, it is called “gamal” and is used for firewood, cattle feedstock and medicine (Dahlanuddin et al. 2014; Knothe et al. 2015; Amirta et al. 2016). Its leaves, fruits, seeds, roots and bark can be toxic for human consumption (Lim 2014; Knothe et al. 2015). It tolerates various soil types, including slightly saline and clay soils (Knothe et al. 2015). There is interest in biofuel production from *G. sepium* as it not only grows fast and tolerates harsh soil conditions, but also has low moisture content, high energy potency, and high carbon and volatile content (Knothe et al. 2015; Amirta et al. 2016).

P. pinnata is a fast-growing leguminous tree of 12–15 m height (Dwivedi and Sharma 2014). In Indonesia, it is called “malapari” and is used for wood, firewood and medicine (Al Muqarrabun et al. 2013; Syamsuwida et al. 2015; Aminah et al. 2017). However, all parts of the plant are toxic for human consumption (Sangwan et al. 2010). It tolerates salinity and drought and grows in a wide range of habitats from humid tropical and subtropical regions to cooler and semiarid zones (Jiang et al. 2012). Many studies have analysed biofuel production from *P. pinnata* as it is nitrogen-fixing, tolerates various habitats and has a high oil yield (Scott et al. 2008; Jiang et al. 2012; Syamsuwida et al. 2015; Siregar and Djam’an 2017).

R. trisperma is a tree of 10–15 m height (Kumar et al. 2015). In Indonesia, it is called “kemiri sunan” and is used as a natural pesticide and fertilizer (Riayatsyah et al. 2017). It is also used for land rehabilitation owing to its capacity to mitigate land erosion. Although one tree can yield about 25–30 kg of seeds per year, they are toxic and inedible (Kumar et al. 2015; Yohana et al. 2016). There is interest in biofuel production from *R. trisperma* oil because of its high oil yield (Holilah et al. 2015; Pranowo and Herman 2016; Riayatsyah et al. 2017).

3.3 Methods

The study methods consisted of two steps. The first step identified degraded lands in Indonesia. The second step analysed the suitability of growing five biofuel species on degraded lands and estimated their potential energy production (Figure 1).

3.1.1 Identification of degraded lands in Indonesia

The first step of the study identified degraded lands in Indonesia. The analysis employed four types of geographic information system (GIS) data to identify potentially degraded land in Indonesia using an overlaying analysis. These data included severely degraded land data, conservation area data, land cover data and land system data (Figure 1). Degraded lands were identified by overlaying these spatial data based on inclusion and exclusion criteria as described below. First, severely degraded land data (DPEPDA 2015) were used to define the initial scope of degraded lands in Indonesia. The data were developed by the Directorate General of Watershed Management and Social Forestry, under the Ministry of Environment and Forestry of Indonesia, based on technical guidelines for the development of spatial data on severely degraded land *(Petunjuk Teknis Penyusunan Data Spasial Lahan Kritis)* set out in Regulation No. P.4/V-SET/2013. These severely degraded lands indicate the degree of land degradation in Indonesia in terms of land cover, slope, potential erosion, land productivity

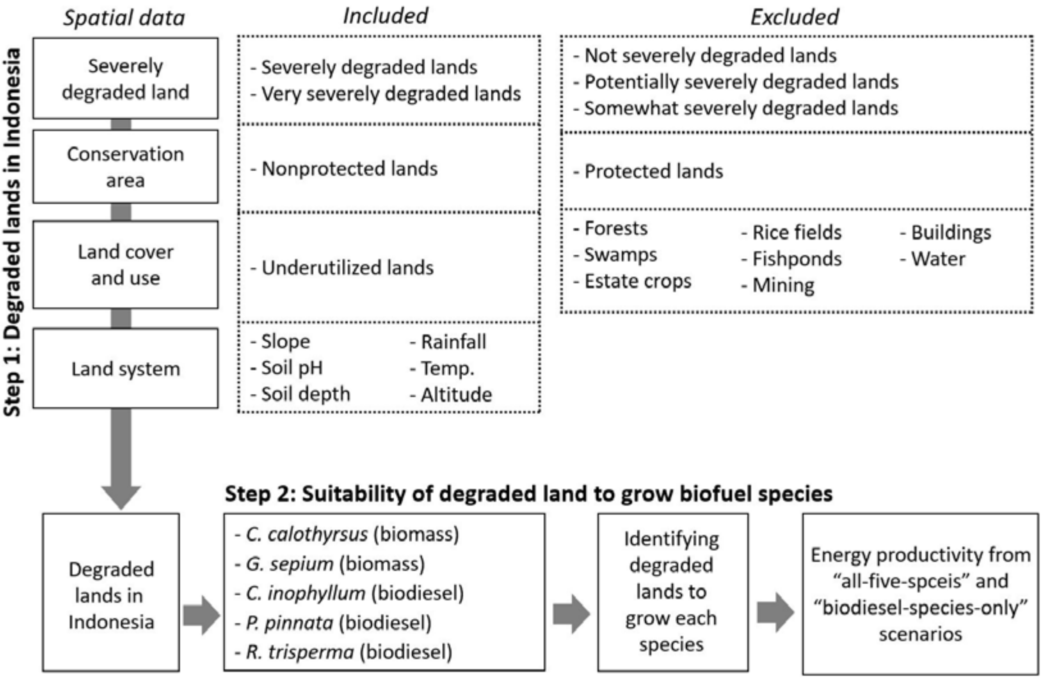

Figure 1. Research methods used to estimate degraded lands in Indonesia and their suitability to grow biofuel species

and land management. The regulation categorizes land degradation as follows: (1) not severe, (2) potentially severe, (3) slightly severe, (4) severe and (5) very severe. Of these categories, this study selected the categories of “severe” and “very severe” to identify the initial scope of degraded lands. Second, conservation area data (DPPKH 2015) were used to exclude protected and conserved forests that prohibit production activities on degraded lands. The data were used to identify protection forest (*Hutan Lindung*) and conservation forest (*Hutan Konservasi*) defined by the Basic Forestry Law, Law No. 41/1999. The law defines protection forest as an area that protects life-support systems by regulating water cycles, maintaining soil fertility, and preventing floods, erosion and saltwater intrusion. Conservation forest is defined as an area that protects life-support systems by preserving biodiversity and utilizing bio-natural resources and ecosystems sustainably. Third, land cover data (DIPSH 2015) were utilized to exclude lands that are used for other purposes and not feasible for biomass production, such as crop estates, forests, swamps, paddy fields, mining areas, fishponds, water bodies and built-up areas. The data were collected from the Indonesian Ministry of Environment and Forestry, where land cover is classified into 23 classes based on the physiognomy or appearance of biophysical cover, which is visually distinguished using the available cloud-free Landsat imagery. Visual classification is carried out by a digitizing on-screen technique using the key elements of image interpretation (MoF 2003). Fourth, land system data (RePPProT 1990) were used to obtain information on slope, pH, rainfall, soil depth, temperature and altitude of the degraded lands. The data were built by the Regional Physical Planning Programme for Transmigration (RePPProT). Land systems are natural ecosystems in which rocks, climate, hydrology, topography, soils and organisms are correlated in a specific way (RePPProT 1990). In addition, missing data of the systems at a regional level were collected from the Land Resources Department (1989).

3.1.2 Suitability of degraded lands to grow biofuel species

The second step of the study analysed the suitability of the degraded lands to grow potential biofuel species and estimated their energy production. Five biofuel species were analysed: *C. calothyrsus*, *C. inophyllum*, *G. sepium*, *P. pinnata* and *R. trisperma* (Table 2). The study categorized suitable lands as highly and moderately suitable lands by applying six conditions of degraded lands in relation to each of the five species: altitude, annual rainfall, temperature, slope, soil pH and soil depth. These lands were defined as being suitable only when the degraded lands fully met all six criteria. These criteria have also been employed by other studies analysing the potential growth of biofuel species on degraded lands in Indonesia (Gingold et al. 2012; Wulandari 2015). In addition, Monte Carlo analysis (e.g., Bryan et al. 2008) was used to estimate the probabilities of each of the degraded land areas to support species growth. The analysis adopted 1,000 simulations applying Gaussian distribution. Suitable lands for the biofuel species were calculated by multiplying the sizes of degraded lands and their probabilities of being suitable lands.

To examine land sizes and parcel numbers, the degraded lands were categorized into small, medium and large sizes. Size categories were developed based on the literature on palm oil

Table 2. Criteria for highly and moderately suitable lands

Attributes[a]	***C. calothyrsus***		***C. inophyllum***		***P. pinnata***		***G. sepium***		***R. trisperma***	
	Highly suitable	**Moderately suitable**	**Highly suitable**	**Moderately suitable**	**Highly suitable**	**Moderately suitable**	**Highly suitable**	**Moderately suitable**	**Highly suitable**	**Moderately suitable**
Annual rainfall (mm)	2,000–4,000	750–2,000 4,000–5,000	2,000–4,000	750–2,000 4,000–5,000	500–2,000	400–500 2,000–2,500	1,200–2,300	600–1,200 2,300–3,500	1,500–2,500 [g]	700–2,500
Temperature (°C)	22–30	18–22 30–34	28–35	10–28 35–42	16–40	10–16 40–50	15–30	12–15 30–44	24–30	18–30 g
Altitude (m)	0–1800	0–1800	0–200	0–200	0–1,200	0–1,200	0–1,600	0–1,600	0–700	0–700
Soil pH	5.0–6.0	4.5–5.0 6.0–7.5	5.5–7.0	5.0–5.5 7.0–8.0	6.5–8.5	6.0–6.5 8.5–9.0	5.5–6.2	4.5–5.5 6.2–8.0	5.4–7.1	>7.1
Soil depth (cm)	50–150	20–50	20–50	20–50	>150	50–150	>150	50–150	>100	50–100
Soil slope (%)	<80 [b]	<80	<30 [c]	<30	<20 [d]	<20	<40 [e]	<40	<8 [f]	8–25

[a] Adopted from Orwa et al. 2009; FAO 2007 and Wulandari 2015

[b] ACTI 1983

[c] Personal communication with Budi Leksono

[d] Miyake et al. 2015

[e] Stewart 1996

[f] Wulandari 2014

[g] CABI 2018

production (Gingold et al. 2012; Lee et al. 2014). In palm oil production, smallholder lands are up to 50 ha (Lee et al. 2014); this criterion was used to categorize small-sized lands for biofuel species production. For industrial palm oil production, 5,000 ha is considered to be the minimum land size (Gingold et al. 2012); this criterion was used to define large-sized lands for biofuel species production. In this study, therefore, "small-sized lands" were lands smaller than 50 ha; "medium-sized lands" were lands bigger than 50 ha but smaller than 5,000 ha; and "large-sized lands" were lands bigger than 5,000 ha. After categorizing the lands with their sizes, the numbers of land parcels were estimated for each land size.

To analyse energy productivity from degraded lands suitable for the selected biofuel species, we developed and investigated two scenarios: (1) the all-five-species scenario, and (2) the biodiesel-species-only scenario. The all-five-species scenario analysed all five of the biofuel species, including those for biodiesel production (*C. inophyllum*, *P. pinnata* and *R. trisperma*) and those for biomass production (*C. calothyrsus* and *G. sepium*). The scenario estimated potential energy productivity from each species assuming that their biomass or seed yields would be lower on moderately suitable land compared with highly suitable land (Table 3). Later, we chose only one species with the highest energy productivity when multiple species were suitable on the same degraded lands so that energy productivity could be maximized from these lands. The biodiesel-species-only scenario was treated using identical analytical procedures, but it only examined those species intended for biodiesel production.

3.4 Results and discussion

3.1.3 Degraded lands in Indonesia

The study results showed Indonesia has approximately 5.8 million hectares (Mha) of degraded land with limited capacity to produce food, sequestrate carbon on land, and maintain vegetation and biodiversity (Figures 2 and 3). Of this land, 72% was categorized as severely degraded and 28% as very severely degraded. The largest area of degraded land was in the Sumatra region, totalling approximately 1.8 Mha. The second largest area was in Kalimantan, totalling around 1.5 Mha, while the smallest area was in the Java and Bali region, at around 0.1 Mha in total.

3.1.4 Degraded land with potential for biofuel production

Of the degraded lands identified, around 3.5 Mha (or 57%) had the potential to grow at least one of the five biofuel species (Figure 3). The distribution of suitable land was slightly different from the distribution of degraded land in general. For instance, the Maluku and Nusa Tenggara region had a larger area of suitable land than Kalimantan. Of these degraded lands, 2.85 Mha were suitable for *C. calothyrsus,* 1.64 Mha for *G. sepium*, 0.21 Mha for *R. trisperma*, 0.14 Mha for *P. pinnata* and 0.05 Mha for *C. inophyllum* (Figures 4 and 5). The area

Table 3. Energy productivity of five potential biofuel species in Indonesia

Attributes	***C. inophyllum***		***R. trisperma***		***P. pinnata***		***C. calothyrsus***		***G. sepium***	
	Highly suitable	**Moderately suitable**	**Highly suitable**	**Moderately suitable**	**Highly suitable**	**Moderately suitable**	**Highly suitable**	**Moderately suitable**	**Highly suitable**	**Moderately suitable**
Biofuel type	Biodiesel	Biodiesel	Biodiesel	Biodiesel	Biodiesel	Bwiodiesel	Biomass	Biomass	Biomass	Biomass
Energy productivity (TJ ha^{-1} yr^{-1})	0.417	0.111	0.040	0.010	0.064	0.006	0.704	0.264	0.089	0.034
Caloric value (MJ kg^{-1})	40.10 [a]	40.10	35.50 [c]	35.50	35.56 [e]	35.56	17.60 [g]	17.60	16.85 [g]	16.85
Biodiesel yield (kg ha^{-1} yr^{-1})	10,400 [b]	2,773	8,000 [d]	6,000	1,800 [f]	180	40,000 [h]	15,000	5,300 [i]	2,000

a Ong et al. 2014

b It was assumed that seed yield per tree would be 150 kg on highly suitable land and 40 kg on moderately suitable land, and 133 trees could be planted per hectare (e.g., maximum 20 tons of seed yield per ha = about 133 trees x 150 kg of seeds) following Leksono et al. (2014). It was also assumed that 65% of seed is oil, and 80% of the oil could be converted to biodiesel (Mohibbe Azam et al. 2005).

c Kumar et al. 2015

d Pranowo and Herman 2016

e Dwivedi and Sharma 2014

f It was assumed that oil yield per hectare would be 2,250 kg for highly suitable land and 225 kg for moderately suitable land (Kumar and Sharma 2011; Atabani and César 2014), and that 80% of oil could be converted to biodiesel (Mohibbe Azam et al. 2005).

g Based on 4,205 kcal per kg for *C. calothyrsus* and 4,027 kcal per kg for *G. sepium* (Amirta et al. 2016)

h Orwa et al. 2009 and Yaliwal et al. 2014

i Stewart et al. 1996

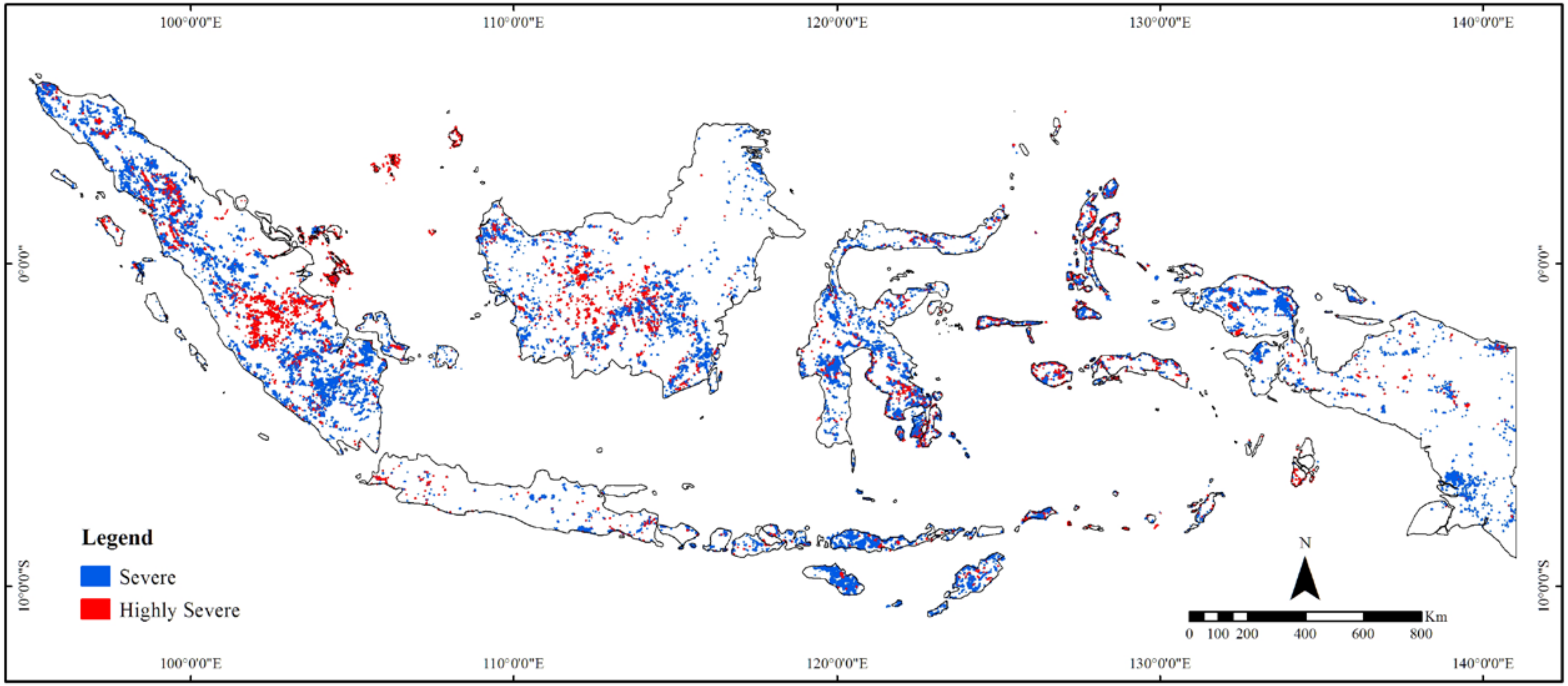

Figure 2. Spatial distribution of degraded lands in Indonesia that have limited functions for food production, carbon storage, and conservation of biodiversity and native vegetation

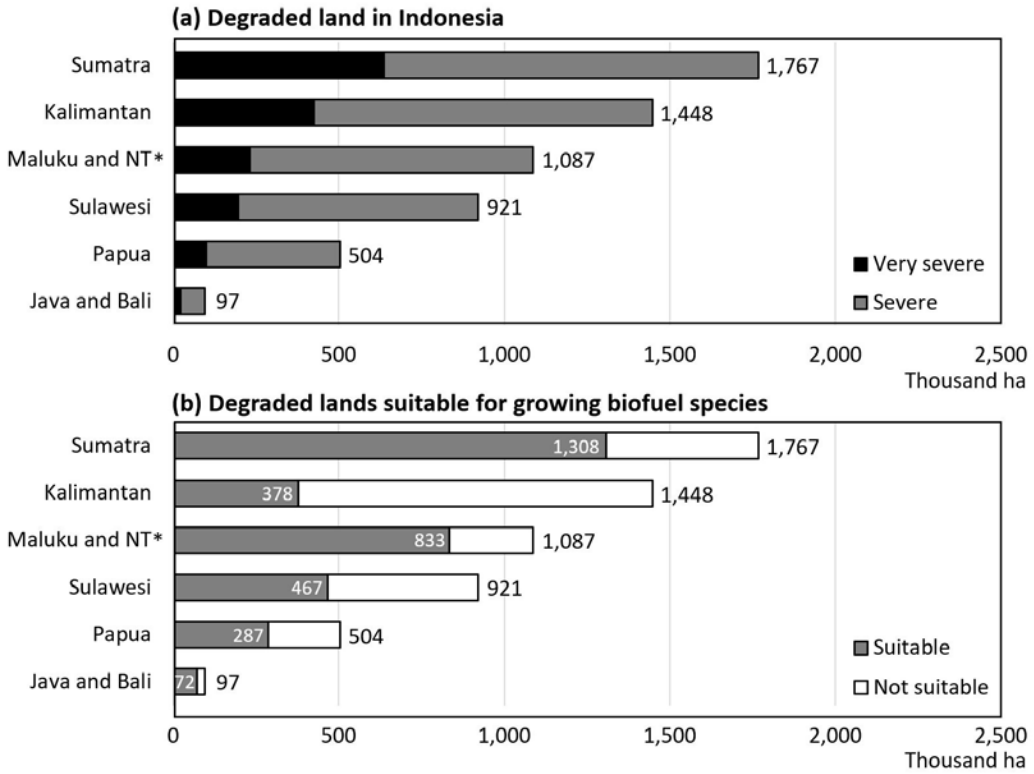

Figure 3. Distribution of degraded lands and lands suitable for growing biofuel species

Note: * Nusa Tenggara

(a) degraded lands in Indonesia identified as having limited functions for food production, carbon storage, and conservation of biodiversity and native vegetation; and (b) degraded lands identified as suitable for cultivating at least one of the following: *C. calothyrsus, G. sepium, C. inophyllum, P. pinnata* and *R. trisperma*.

of highly suitable land was significantly smaller than of moderately suitable land for these species. At 4.49 Mha, land suitable for biomass species (*C. calothyrsus* and *G. sepium*) was approximately 11 times larger than the 0.4 Mha of land suitable for biodiesel species (*C. inophyllum, P. pinnata* and *R. trisperma*).

The degraded lands were analysed in terms of their sizes and numbers of parcels (Figure 6). Small-sized lands (less than 50 ha) consisted of 81% of the total number of land parcels, but their areas were only 8% of the total area of degraded lands. Medium-sized lands (between 50 and 5,000 ha) represented 19% of the total number of parcels, but comprised 70% of the total land area. Large-sized lands (larger than 5,000 ha) comprised only 0.1% of the total number of land parcels, but represented 22% of the total area of degraded lands.

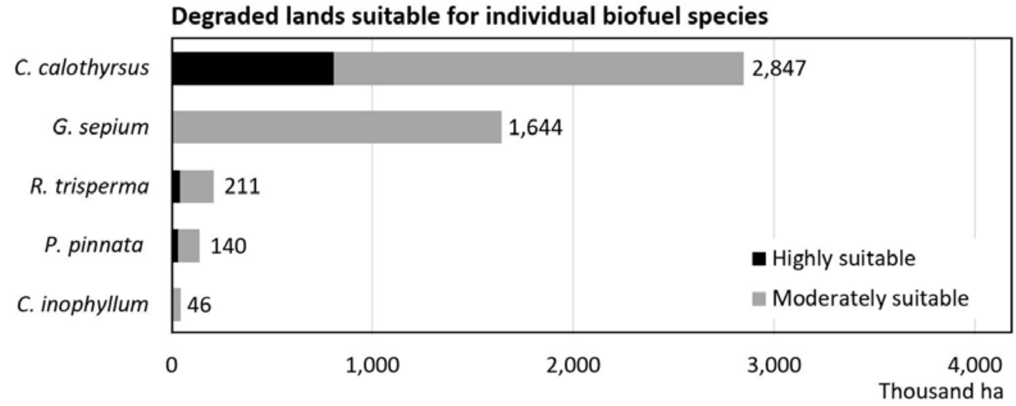

Figure 4. Total area of degraded lands in Indonesia identified as suitable for growing individual biofuel species

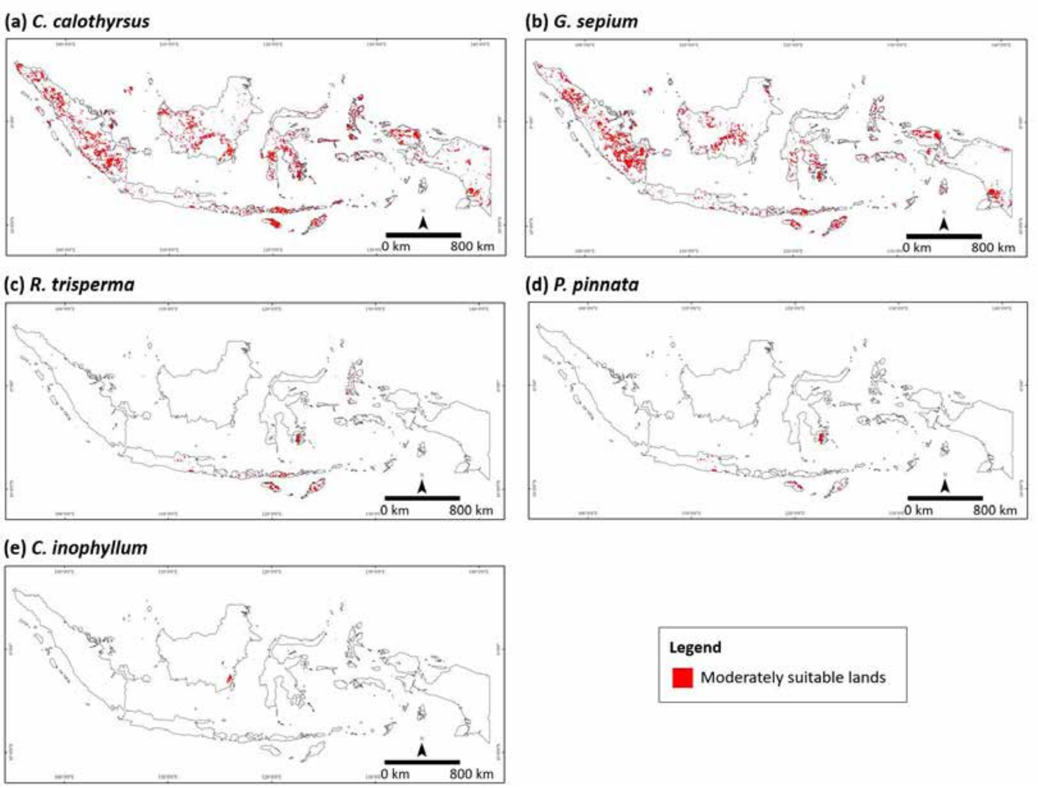

Figure 5. Comparison of degraded lands in Indonesia that are moderately suitable for cultivating *C. calothyrsus, G. sepium, R. trisperma., P. pinnata* and *C. inophyllum*

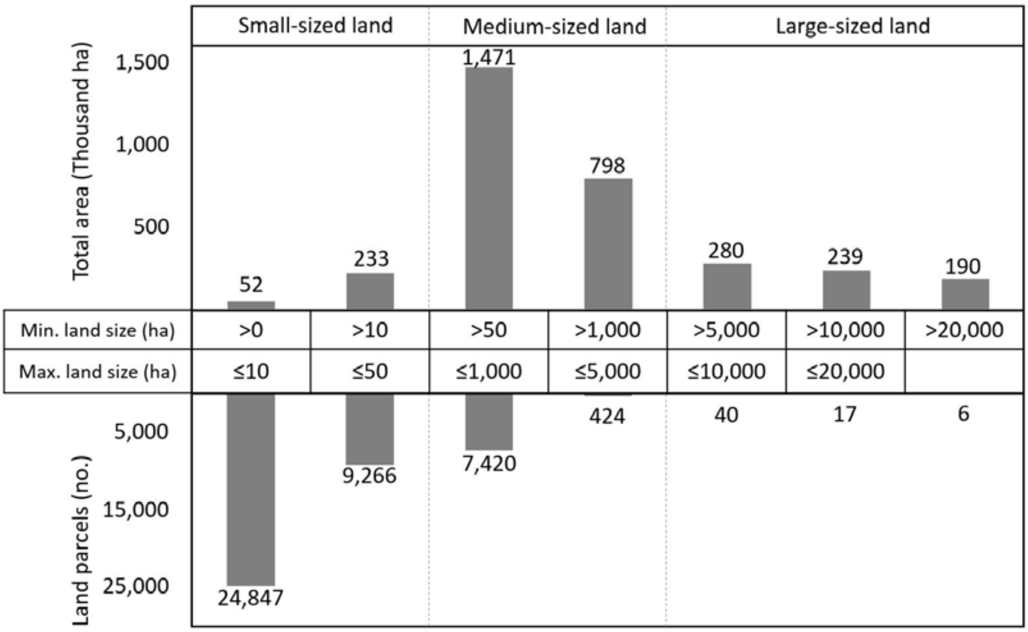

Figure 6. Total area and numbers of land parcels for small-, medium- and large-sized degraded lands in Indonesia suitable for at least one of the biofuel or biomass species (*C. calothyrsus, G. sepium, C. inophyllum, P. pinnata* and *R. trisperma*)

3.4.1 Scenario analyses

The all-five-species scenario, assessing all the biofuel species, resulted in the identification of land suitable for growing *C. calothyrsus*, *P. pinnata*, *R. trisperma*, *G. sepium* and *C. inophyllum* (Figure 7). Of the species assessed, *C. calothyrsus* had the largest area of suitable land (2.8 Mha), not only because it was the most suited to the degraded lands (Figure 4), but also because it had the highest potential energy productivity compared to other species (Table 3). The largest area of land identified as being suitable for this species was in the Sumatra region (0.93 Mha), while the smallest area was in Java and Bali (0.07 Mha). Degraded lands identified as suitable for other species under this scenario were smaller in area: *G. sepium* had 430,002 ha of suitable land; *P. pinnata* had 30,559 ha; *R. trisperma* had 21,013 ha; and *C. inophyllum* had only 132 ha. This scenario resulted in about 1.105 exajoules per year (EJ yr^{-1}) of hypothetical maximum energy productivity (Table 4). The energy productivity from biomass was about 1.102 EJ yr^{-1} (99%), while that from biodiesel was only about 0.003 EJ yr^{-1}. This biomass energy was equal to about 59% of the total biomass consumption in Indonesia in 2016 (ESDM 2017) (Table 5). With an assumption of 30% of this biomass being converted to electricity, it might produce 0.331 EJ yr^{-1}, which is equivalent to around 38% of Indonesia's electricity production in 2014 (0.865 EJ yr^{-1}) (IRENA and ACE 2016).

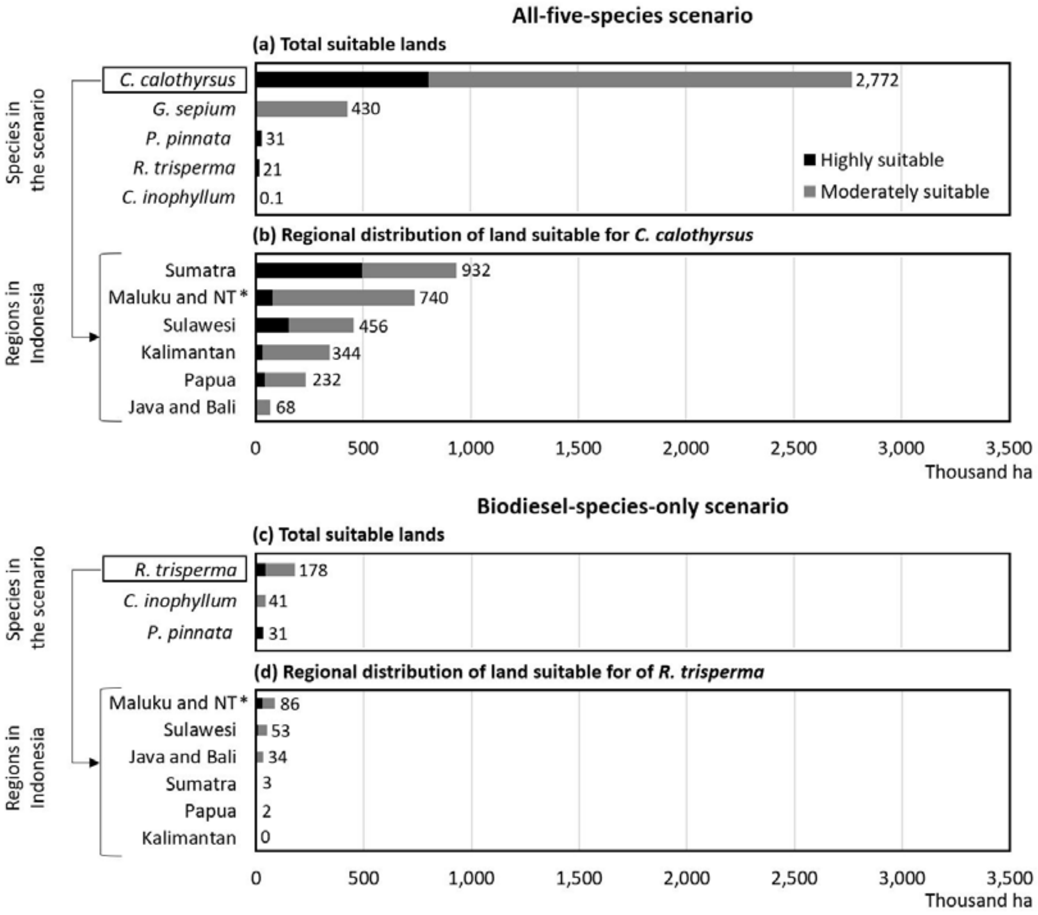

Figure 7. Total area of degraded lands in Indonesia identified as suitable for the all-five-species and biodiesel-species-only scenarios
(Note: * Nusa Tenggara)

The biodiesel-species-only scenario, assessing biodiesel species only, resulted in the identification of lands suitable for *R. trisperma, C. inophyllum* and *P. pinnata* (Figure 7). Of these species, *R. trisperma* had the largest potential, with around 0.18 Mha of suitable lands. These lands were distributed across several regions, though no suitable land was found in the Kalimantan region. Under this scenario, *C. inophyllum* and *P. pinnata* had only 40,625 ha and 30,739 ha of suitable lands, respectively. The scenario resulted in hypothetical maximum energy productivity of around 0.01 EJ yr^{-1} (Table 4). This energy is equal to around 2% of total automotive diesel oil consumption in Indonesia in 2016 and around 634% of total industrial diesel oil consumption (ESDM 2017) (Table 5).

Both scenarios demonstrate opportunities and challenges for Indonesia in using degraded lands to help achieve its target of ensuring biodiesel accounts for 30% of total energy consumption by 2025 as mandated by Presidential Regulation No. 12/2015 (GAIN 2017).

Table 4. Potential energy production (TJ yr^{-1}) of selected biofuel species from degraded lands in Indonesia

Species	**Type**	**Highly suitable lands**	**Moderately suitable lands**	**Total**
All-five-species scenario				1,104,598
a) Biomass total		568,867	532,921	1,101,787
C. calothyrsus	Biomass	568,494	518,443	1,086,937
G. sepium	Biomass	373	14,478	14,851
b) Biodiesel total		2,796	15	2,811
R. trisperma	Biodiesel	1,956	0	1,956
P. pinnata	Biodiesel	841	0	841
C. inophyllum	Biodiesel	0	15	15
Biodiesel-species-only scenario				9,661
a) Biodiesel total		3,852	5,809	9,661
C. inophyllum	Biodiesel	229	4,448	4,678
R. trisperma	Biodiesel	1,655	1,361	3,016
P. pinnata	Biodiesel	1,967	0	1,967

Table 5. Comparison between the biofuel production scenarios and 2016 energy consumption in Indonesia

Energy consumption in 2016*		**All-five-species scenario**		**Biodiesel-species-only scenario**
Energy type	**Energy (TJ yr^{-1})**	**Biomass % (1,101,787 TJ yr^{-1})**	**Biodiesel % (2,811 TJ yr^{-1})**	**Biodiesel % (9,661 TJ yr^{-1})**
Biomass	**1,878,159**	**59**	**NA**	**NA**
Household	1,610,349	68	NA	NA
Industrial sector	259,611	424	NA	NA
Commercial sector	8,198	13,440	NA	NA
Automotive diesel oil	**567,812**	**NA**	**0.5**	**2**
Transportation sector	282,450	NA	2	6
Industrial sector	172,809	NA	11	39
Other sectors	87,671	NA	1	3
Commercial sector	24,882	NA	3	11
Industrial diesel oil	**1,523**	**NA**	**185**	**634**
Industrial sector	1,279	NA	220	756
Other sectors	190	NA	45,946	157,915
Transportation sector	49	NA	5,743	19,739
Commercial sector	6	NA	1,482	5,094

* Source: ESDM (2016)

Both scenarios showed potential to support Indonesia in achieving its biodiesel consumption target. The all-five-species scenario indicated the potential to produce biodiesel energy equivalent to around 0.5% of automotive diesel oil consumption in Indonesia in 2016 and in excess of industrial diesel oil consumption (Table 5). In addition, if 30% of the biomass produced were converted to electricity, it might produce 0.331 EJ yr^{-1}, which is equivalent to around 38% of Indonesia's electricity production in 2014 (0.865 EJ yr^{-1}) (IRENA and ACE 2016). The biodiesel-species-only scenario showed the potential to produce biodiesel energy equivalent to around 2% of automotive diesel oil consumption in Indonesia in 2016 and in excess of industrial diesel oil consumption. Considering Indonesia's biofuel production was only 3.66 billion litres in 2016 or 0.05% of its total fuel consumption (70 billion litres) (GAIN 2017), these study findings suggest producing biofuels on degraded lands might help Indonesia increase the biofuel percentages in its total energy consumption.

However, these lands might be limited in their ability to support economies of scale for biofuel production and only reflect a hypothetical maximum land area. The sizes of many degraded lands were smaller than 5,000 ha, which is considered the minimum land size on which economies of scale from palm oil production can be achieved (Gingold et al. 2012). Although palm oil is not solely used for biofuel production, lessons from palm oil production would support growth of other biofuel species since palm oil has been used as a dominant biofuel species in Indonesia (Harahap et al. 2017). Thus, the sizes of these degraded lands must be considered in analysing their potential business models for bioenergy production in Indonesia. Furthermore, study results indicate maximum energy productivity potential, as the study assumed all degraded lands would be utilized for biofuel production by growing the five biofuel species. In reality, however, this bioenergy production would be diminished by many socioeconomic factors, such as the production cost–benefit to farmers and refineries (Bryan et al. 2008; ICCC 2014; Maraseni and Cockfield 2015), higher opportunity costs for bioenergy production compared with palm oil production (Gingold et al. 2012) or other biofuel species such as sugarcane (ICCC 2014; Neupane et al. 2017), competition with low-price energy such as gasoline (ICCC 2014) and conflicted stakeholder interests (Colchester et al. 2006). Furthermore, this energy would be reduced further when converted into other forms, such as electricity, for final consumption. These factors are likely to reduce the biofuel production estimates from this study, and should be analysed further to fully understand how many of these degraded lands might in reality support bioenergy production in Indonesia.

3.5 Conclusions

The study identified 3.5 Mha of degraded lands in Indonesia that could be used for growing biodiesel species (*C. inophyllum*, *P. pinnata* and *R. trisperma*) and biomass species (*C. calothyrsus* and *G. sepium*) to support bioenergy production without compromising food production, carbon storage, biodiversity and native vegetation. Study results revealed both opportunities and challenges for bioenergy production from these degraded lands. The two-scenario analysis showed that maximum production from *C. calothyrsus* and *G. sepium* could produce biomass energy equal to 59% of Indonesia's total biomass consumption in 2016, while production from both scenarios could produce biodiesel energy equal to 0.5–2% of its 2016 automotive diesel oil consumption. However, the sizes of degraded lands were too small to support economies of scale for biofuel production, and in reality, these maximum production figures would be diminished by numerous socioeconomic factors. These findings may support future studies modelling biofuel species cultivation and comparisons with carbon sequestration potential from the restoration of degraded lands.

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CHAPTER 4

Landowner perceptions towards bioenergy production on degraded lands in Indonesia

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Abstract: Various tree species have been identified as having potential for bioenergy and restoration of degraded land. Using degraded land for bioenergy production provides Indonesia with an opportunity to meet its rapidly growing energy demand while creating productive landscapes. However, bioenergy production is not feasible without landowner participation. This study investigates factors affecting preferences for restoration tree species by analysing responses from 150 landowners with fire experience in Buntoi Village in Central Kalimantan l. Results indicate 76% of landowners preferring familiar species with readily available markets, such as *Albizia chinensis* (*sengon*) and *Hevea brasiliensis* (rubber), for restoration on degraded land, with only 8% preferring *Calophyllum inophyllum* L. (*nyamplung*) for bioenergy production. The latter group of landowners revealed a capacity to handle the uncertainty of the bioenergy market as they had additional jobs and income, had migrated from Java where *nyamplung* is prevalent, or preferred agricultural extension to improve their technical capacity. These results contribute to identifying key conditions for a bottom-up approach to bioenergy production on degraded land in Indonesia: a stable bioenergy market for landowners, application of familiar bioenergy species, and agricultural extension support for capacity building.

Keywords: bioenergy, renewable energy, degraded land, farmer perceptions, restoration
Link: https://www.cifor.org/knowledge/publication/7129
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4.1 Introduction

Bioenergy is a promising and most versatile form of renewable energy (Ladanai et al. 2009; WEC 2016), and its production from degraded lands has potential for helping meet global energy demand (Campbell et al. 2008; Cai et al. 2011). It might increase the supply of renewable energy (Cai et al. 2011) and improve land use efficiency (Tilman et al. 2006; Fargione et al. 2008). These benefits have encouraged many countries to promote bioenergy use and support the development of technologies and policies related to bioenergy production (Ladanai et al. 2009; WEC 2016). The Government of Indonesia, for example, has set targets to increase biodiesel and bioethanol use by 30% and 20%, respectively by 2025 (Presidential Regulation No. 12/2015) (Gain 2017) to manage the country's rapidly growing energy demand. By 2025, energy demand in Indonesia is expected to be 1.8 times higher than in 2015 (GoI 2014) due to population growth, urbanization and economic development (ICCC 2015; DEN 2017; Jaung et al. 2018).

Recently, there has been increasing interest in bioenergy production through the cultivation of non-food seed oil producing crops such as *Calophyllum inophyllum* (*nyamplung*) on degraded lands. Such practices can have multiple benefits (Samsudin et al. 2018) as some of these non-food crops can grow on degraded lands unable to support food production, thereby minimizing the trade-off between food and fuel production (Leksono et al. 2014; Borchard et al. 2017; Widayati et al. 2017; Bustomi et al. 2018). Environmental impacts can be reduced if these crops are harvested from degraded and underutilized lands that have limited value to store carbon and preserve native vegetation and biodiversity (Leksono et al. 2014; ICCC 2015; Rahman et al. 2019). In addition, such practices could support restoration of degraded lands with these bioenergy species and provide a variety of ecosystem services, such as carbon storage, soil erosion reduction and biodiversity enhancement (Singh et al. 2015; Blanco-Cangui 2016). They also create employment opportunities in rural areas, particularly in developing countries where large populations live and rely on marginal lands for farming (Liu et al. 2011; Dauber et al. 2015; Ullah et al. 2015; Widayati et al. 2017).

However, capturing the benefits of bioenergy production on degraded land is not feasible without landowner participation. Therefore, to make bioenergy production an attractive prospect for landowners, it should meet their preferences and expectations. In 2007, the Government of Indonesia launched its *Desa Mandiri Energi* or energy self-sufficient villages programme in Java (Amir et al. 2008; Singh and Setiawan 2013; Simandjuntak 2014; Uripno et al. 2014; Fatimah 2015; Muslihudin et al. 2015). The programme aimed not only at encouraging village communities to produce bioenergy for energy security, but also at creating employment and reducing poverty in rural areas. However, most pilot projects under the programme have recently been discontinued as its top-down approach failed either to engage landowners or accommodate their preferences. This failure suggests a bottom-up approach would be preferable; one that motivates landowners to participate in bioenergy production, ensures stable market demand for bioenergy feedstocks, and reflects local needs. A preliminary step in testing the feasibility of such a bottom-up approach is to investigate what would encourage or discourage owners of degraded and underutilized land to participate in bioenergy production.

This study examines landowner perceptions of bioenergy production from degraded land in Buntoi Village in Central Kalimantan, Indonesia, and investigates sociodemographic factors affecting their preferences for bioenergy production. Several studies, such as Amir et al. (2008), Feintrenie (2010) and Anggraini and Grundmann (2013), have analysed bioenergy production from degraded land in Indonesia. Though few have focused on the owners of degraded lands, or on landowner preferences for non-food species to restore degraded lands and produce bioenergy feedstocks (Sitompul et al. 2016). Thus, limited empirical evidence is available to elucidate factors affecting landowner preferences for bioenergy production from degraded land in Indonesia. This study attempts to reduce this knowledge gap by identifying particular factors influencing landowners in Central Kalimantan, and to contribute to our understanding of the feasibility of developing a bottom-up approach to bioenergy production from degraded land in Indonesia.

4.2 Bioenergy production in Indonesia

4.2.1 Landowner preferences

Several studies identify factors affecting landowners' preferences for bioenergy species such as *Elaeis guineensis* (Jacq.) (oil palm) *Jatropha curcas* (jatropha) and *Calophyllum inophyllum* L. (*nyamplung*) in Indonesia. Feintrenie et al. (2010) argue that factors affecting smallholder preferences for palm oil in Jambi, Sumatra, may include direct profits, low technical requirements to grow oil palm, high investment return, and partnerships with large companies and banks. Anggraini and Grundmann (2013) assert that cash income and loans were major motivations for smallholders in Mandailing Natal and Labuhan Batu districts in North Sumatra in converting their rice fields for oil palm. Amir et al. (2008) argue that expectations of high profits motivated farmers in Mandalasari Village, West Java to plant jatropha in their mixed gardens and rice fields. Uripno et al. (2014) indicate that factors affecting communities' involvement in bioenergy production in Buluagung and Patutrejo villages in Central Java included bioenergy price, technology innovation, project roles and support from local leaders. Sitompul et al. (2016) indicate that the likelihood of farmers in Maliku and Pandih Batu subdistricts in Central Kalimantan taking up bioenergy production would increase with higher profits and shorter contracts. They also argue that farmers from different ethnic backgrounds would have different interests in bioenergy crops. Nurlaila et al. (2013) assert that landowners' traditions and cultures impact their decisions regarding bioenergy production.

As these studies are mostly qualitative and investigate the overall preferences of stakeholders for bioenergy, their results are limited in providing empirical representations of the various owners of degraded lands. Thus, quantitative analyses that focus on such landowners are needed to gain a more comprehensive understanding of their preferences and expectations in regard to bioenergy production.

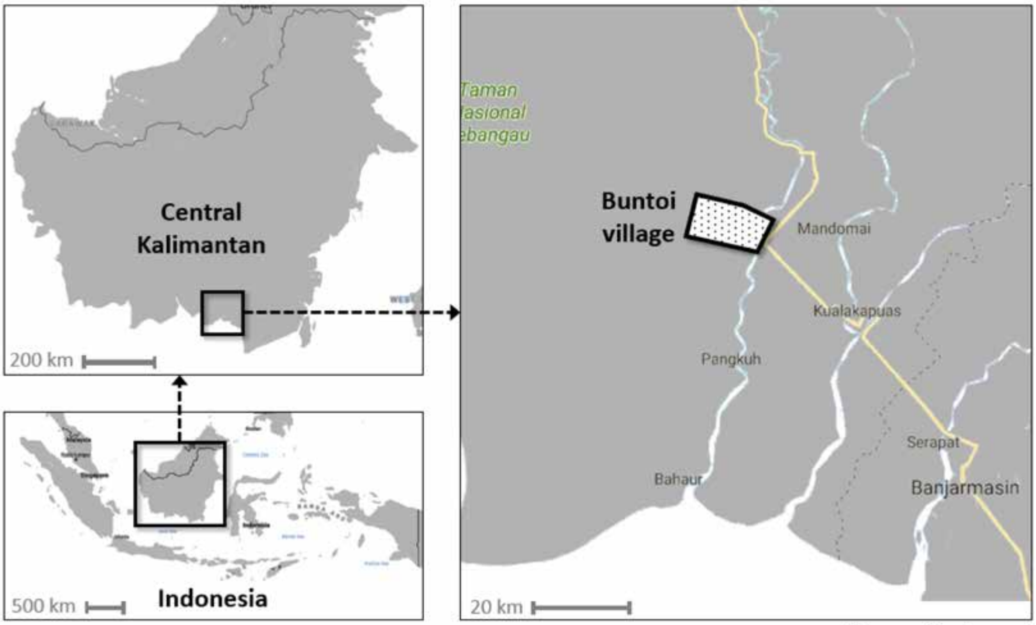
4.2.2 Challenges in encouraging landowner participation

The Energy Self-Sufficient Villages programme reveals several challenges for landowners who produce or wish to produce bioenergy feedstocks in Indonesia (Simandjuntak 2014; Uripno et al. 2014; Fatimah 2015; Muslihudin et al. 2015). Although relevant to various stakeholders in bioenergy production, these challenges reflect required conditions for landowners, including: a bottom-up approach allowing their participation during programme development; a stable market in which to sell bioenergy feedstocks; capacity building and technical guidelines; stable and high levels of production of bioenergy feedstocks; low cost of bioenergy production; low levels of stakeholder conflicts; technical advancement of bioenergy production; and available infrastructure. Muslihudin et al. (2015) indicate that implementation of the programme was challenged by low levels of community engagement, inefficient machinery for bioenergy feedstock processing, limited technical guidelines, high production costs and a limited market in which to sell seed oil. Uripno et al. (2014) assert that the top-down nature of the programme challenged the long-term participation of communities. Simandjuntak (2014) demonstrates that the programme was challenged by a limited market, unstable crop production and limited technical research. Fatimah (2015) shows that stakeholders considered low productivity and poor coordination between institutions to be the main reasons for the programme's failure. Amir et al. (2008) argue that complex bureaucracy at the village level and different stakeholder interests were major challenges to programme implementation. They also claim that limited land for growing bioenergy crops was a major challenge in encouraging small landowners to participate in bioenergy production. All of these challenges provide valuable lessons for testing the feasibility of a bottom-up approach to bioenergy production on degraded land in Indonesia.

4.3 Materials and methods

4.3.1 Study site

The research site is located in Buntoi Village, Pulang Pisau District, Central Kalimantan Province at coordinates 2°48'59.4" S and 114°10'47.3" E along the Kahayan, one of the main rivers in the province (Figure 1). Buntoi Village covers a total area of approximately 16,000 ha. Agriculture and forest land use dominate the area, accounting for 41% and



(Source: Google map)

Figure 1. Location of Buntoi Village, Central Kalimantan, Indonesia

57%, respectively, while the remaining 2% constitutes settlements. Rubber production has been a major economic activity in Buntoi. The village has a tropical humid climate with average temperatures ranging from 26.5 to 27.5°C (Buntoi Village Government 2014). Consisting of 12 sub-villages, the village had a total population of 2,719 at the time of the study. The predominant ethnic group in the village is Ngaju Dayak, but other ethnicities include Banjarese, Javanese, Batak, Buginese, Sundanese, Madurese, Balinese, Florinese, Manadonese and Chinese (Buntoi Village Government 2016).

Buntoi Village was selected as a study site because it has large areas of burned degraded land and is a pilot location for the central and regional government's *Bioenergy Lestari* sustainable bioenergy programme. In 2015, the village was one of a number of areas affected by massive forest fires, the haze from which affected neighbouring countries, including Singapore and Malaysia. Fire destroyed more than 400 ha of landowners' rubber plantations in the village, resulting in losses of around IDR 300 million, equivalent to USD 22,500 in 2017 (Buntoi Village Government 2015). With landowners seeking ways to invest in their burned lands, the Ministry of Energy and Mineral Resources initiated the *Program Pengembangan Bioenergi Lestari* or Sustainable Bioenergy Development Programme in collaboration with the Central Kalimantan Provincial Government to produce bioenergy from degraded lands in the districts of Pulang Pisau and Katingan, including Buntoi Village.

4.3.2 Survey design and administration

We designed a survey to analyse landowners' preferences for restoration species for degraded lands and their perceptions of bioenergy. Prior to designing the survey, we conducted a preparatory visit in June 2016 to observe village conditions and interview key village informants about the 2015 fire and haze disaster, rubber plantation costs and current market conditions, and landowners' plans for restoring their burned lands.

As a result of the visit, three species were selected as potential restoration species for the village: *sengon* (*Albizia chinensis*), rubber tree (*Hevea brasiliensis*) and *nyamplung* (*Calophyllum inophyllum* L.). *Sengon* was chosen for timber production, as it was gaining increasing recognition in the village as a high-value species. In addition, the Ministry of Environment and Forestry was supporting *sengon* production through its *Hutan Kemasyarakatan* (HKM) social forestry programme. Through this programme, the government grants 35-year community plantation forest timber extraction permits (IUPHHK-HTR) for farmers to harvest wood. Rubber tree was selected as rubber production had been a major economic interest in the village for many years, and villagers traditionally used old rubber trees as fuelwood for cooking. *Nyamplung* was selected as a potential species for bioenergy production. As the bioenergy species was new to the village, it was considered appropriate for testing landowners' perceptions regarding potential for bioenergy production. *Nyamplung* is known to produce the biodiesel most similar to diesel oil, has the potential to replace diesel fuel without the need for engine modifications (Ong et al. 2011), and adapts well to degraded land including peatland (Maimunah et al. 2018). In addition, it meets the Indonesian National Standard (SNI) for fuel (Leksono et al. 2014; Bustomi et al. 2018).

The final survey had sections on demographic information, land management plans, fire coping strategies and perceptions on bioenergy. Questions in the first section focused on essential sociodemographic information, including level of education, household earnings and ethnic background. The second section asked respondents about their experiences with land degradation resulting from fire. The third section asked about strategies for managing degraded farmland, while the fourth section asked participants to choose which one of the three species (Table 1) they would prefer for restoration of their degraded lands. Participants were also allowed to opt for none of the three species. Before being asked about their preferences, each participant received a brief presentation on the main characteristics of the three species based on a literature review and expert consultations. Visual aids were used to increase understanding when providing species descriptions.

From 29 January to 7 February 2017, we surveyed a total of 150 owners of land in Buntoi Village degraded by the 2015 forest fire. Respondents were selected randomly

Table 1. Characteristics of the three potential restoration species for degraded land in Buntoi Village

Category	***Sengon***	**Rubber tree**	***Nyamplung***
Main objective	Timber production (1)	Rubber production (2)	Biodiesel production (3, 4)
Other uses	Fuelwood, wooden crates, animal feed (1)	Fuelwood (2, 8)	Medicine, cosmetics, wood, fuelwood, and animal feed (3)
Tolerable conditions	Infertile and moist land (1)	Fertile land (5)	Infertile and waterlogged land (6)
Disease resistance	Weak (1)	Weak (5)	Medium (1)
Capacity to improve soil	Strong (1)	Medium (2)	Strong (7)
Market availability	Available (8)	Available (8)	Limited (9)
Price risk	Not influenced by international market (9)	Influenced by international market (10)	Not influenced by international market (9)
Plantation cost per ha *	IDR 30 million (9)	IDR 12.5 million (8)	IDR 10 million (3)
Revenue per ha	IDR 120–130 million (wood) (9)	IDR 13–39 million (rubber) (8)	IDR 20–22 million (seed) (3)
First harvest after planting	5th year (9)	7th year (8)	7th year (3)
Harvest cycle	Once every 5 years (9)	Every year (8)	Every year (3)
Production period	For 5 years (9)	For 50 years (8)	For 50 years (3)

Sources: (1) Pratiwi et al. 2014; (2) Orwa et al. 2009; (3) Leksono et al. 2014; (4) Ong et al. 2011; (5) Damanik et al. 2010; (6) Martawijaya et al. 2005; (7) Friday and Okano 2016 [42]; (8) Interviews with key informants in the preparatory visit in 2016; (9) consultations with *sengon* silviculture and business experts in Kalimantan and Java; and (10) Zhengzhou Double Vigour Chemical Product Co. Ltd. 2013. * IDR = Indonesian rupiah. Per September 2017, IDR 13,510 = USD 1.

from the 10 sub-villages where most landowners with forest fire experience reside. Sociodemographic variables of participants are presented in Table 2.

In addition, a focus group discussion was held with key informants in Buntoi to examine village land-use history, environmental changes the village has experienced, and landowners' plans for their degraded lands. Key informants were identified through snowball sampling and invited to the discussion. A total of 20 key informants comprising sub-village representatives and those actively involved in village activities joined the focus group discussion.

Table 2. Sociodemographic variables of landowners with degraded lands in Buntoi Village (n = 150)

Variable	Mean	Standard Deviation
General information		
Gender (male: 1, female: 0)	0.78	0.42
Education (years)	8.77	3.09
Age (years)	47.65	13.59
Business income (yes: 1, no: 0)	0.15	0.35
Monthly household income (IDR)	3,191,512	3,489,856
River water use (yes: 1, no: 0)	0.06	0.24
Land use		
Mainly farming (yes: 1, no: 0)	0.76	0.43
Farming with another job (yes: 1, no: 0)	0.24	0.43
Burned land in 2015 (ha)	3.48	3.90
Ethnic group		
Dayak (yes: 1, no: 0)	0.77	0.42
Banjarese (yes: 1, no: 0)	0.19	0.40
Javanese (yes: 1, no: 0)	0.03	0.16
Madurese (yes: 1, no: 0)	0.01	0.08

Means of the dummy variables (1 or 0) represent their percentages in variable categories: male (78%) or female (22%); having business income (15%) or not (85%); farming as main income source (76%) or additional income source (24%); using river water (6%) or not (94%); and ethnicity of Dayak (77%), Banjarese (19%), Javanese (3%) and Madurese (1%).

4.3.3 Firth's logistic regression

We established a binary logistic regression model to analyse the impacts of sociodemographic variables on landowners' decisions to plant a potential bioenergy species (*nyamplung*) on their degraded land. We defined *E* (*y*|*X*) as an expected probability for landowners to select *nyamplung* (*y*) given their sociodemographic values (*X*), resulting in a logistic regression model:

$$\boldsymbol{ln}\left[\frac{\boldsymbol{E(y\,|\,X)}}{\boldsymbol{1+E(y\,|\,X)}}\right] = \boldsymbol{\beta_0 + \beta_1 x_1 + \cdots + \beta_6 x_6}, \tag{1}$$

where b_0 is an intercept, x_1 is "farming with another job," x_2 is "business income," x_3 is "Javanese," x_4 is "Bioenergy benefit for climate," x_5 is "extension to learn," x_6 is "river water use," and b_1 to b_6 represent coefficients of the six variables. The model was estimated with Firth's penalized likelihood (Feintrenie 2010) since only a small number of landowners selected *nyamplung* (*n* = 12). Logistic regression models with a small number of events might result in inflated coefficients and separation indicating that dependent variables are perfectly separable using an independent variable. A solution to these problems is Firth's logistic regression, which penalizes likelihood estimation (Firth 1993; Heinze and Schemper 2002; Wang 2014; Heinze and Ploner 2016). It penalizes inflated coefficients by using a score function:

$$U(\boldsymbol{\beta_n})^* = U(\boldsymbol{\beta_n}) + \mathbf{0.5}\boldsymbol{tr}\left[\boldsymbol{I}(\boldsymbol{\beta})^{-1}\frac{\partial \boldsymbol{I}(\boldsymbol{\beta})}{\boldsymbol{\beta_n}}\right] \qquad n = 1,\ldots, k, \qquad (2)$$

where, b_n indicates the *n*th parameter, *k* is the number of parameters, *tr* is the trace function, and *I(b)* is the Fisher information matrix. Before finalizing the model, we tested the collinearity of the selected variables and their potential interactions. For the model estimation, the study employed R version 3.4.1 software and the ‘logistf’ package (Heinze and Ploner 2016).

4.4 Results

4.4.1 Landowner perceptions of bioenergy

Results showed that landowners in Buntoi Village preferred to use conventional species for restoration of their degraded lands and had low awareness of bioenergy. A majority (57%) preferred *sengon* as a potential restoration species (Figure 2a), while 19% chose rubber, with *nyamplung* being the least preferred species at 8%. When asked about preferred modes of learning about selected restoration species, most landowners chose following other farmers (*n* = 48), followed by searching for information themselves (*n* = 35), and learning by agricultural extension (*n* = 30) (Figure 2b). Meanwhile, 12 landowners preferred learning by practice. Of the 150 landowners, only 32 (23%) were aware of bioenergy and renewable energy before the survey, having found out from the media (*n* = 12), neighbours (*n* = 9), non-governmental organizations (NGOs) (*n* = 9), and the government (*n* = 5) (Figure 2c). Many thought bioenergy would provide economic benefits (*n* = 27), help mitigate climate change (*n* = 19), conserve soil (*n* = 9) and conserve water (*n* = 2) (Figure 2d).

4.4.2 Logistic regression model

Two Firth logistic regression models were established (Table 3). Model 1 obtained variables significant at the 1% level, while Model 2 obtained variables that were either statistically significant or insignificant. Since Model 2 failed to reject the null hypothesis of the Wald test (impacts of all variables were equal to zero), Model 1 was mainly used to interpret results.

Results of Model 1 revealed characteristics of landowners who had chosen to plant *nyamplung* as a plantation species on their degraded lands (Table 3). All variables had p-values lower than 1%. A likelihood ratio test of the model was significant at the 1% level, and a Wald test with all variables of the model was significant at the 5% level. The model only analysed the main effects of the selected variables because none of their interactions were statistically significant. The model avoided collinearity as none of the selected variables were correlated to each other.

Table 3. Results of the Firth logistic regression model showing landowner preferences for bioenergy production on degraded lands (n = 150)

	Model 1		Model 2	
Variables	Coeff^1.	Std. error^2	Coeff^1.	Std. error^2
Intercept	−7.738 **	1.876	−4.303 **	2.509
Farming with another job	3.013 **	1.202	3.856 **	1.525
Business income	3.950 **	1.251	4.155 **	1.446
Javanese	5.776 **	2.186	6.116 **	2.444
Bioenergy benefit for climate	2.583 **	1.086	2.833 **	1.127
Agricultural extension	3.193 **	0.969	3.141 **	1.063
River water use	5.215 **	2.044	5.228 *	2.082
Age			−0.035	0.041
Gender			−0.540	0.944
Education			−0.197	0.173
Burned land area			−0.012	0.081
Likelihood ratio test	$\chi^2 = 48.52$, $p < 0.001$		$\chi^2 = 47.91$, $p < 0.001$	
Wald test	$\chi^2 = 14.59$, $p = 0.023$		$\chi^2 = 13.96$, $p = 0.187$	

** Significant at the 1% level. * Significant at the 5% level. 1 Coefficient, 2 Standard error

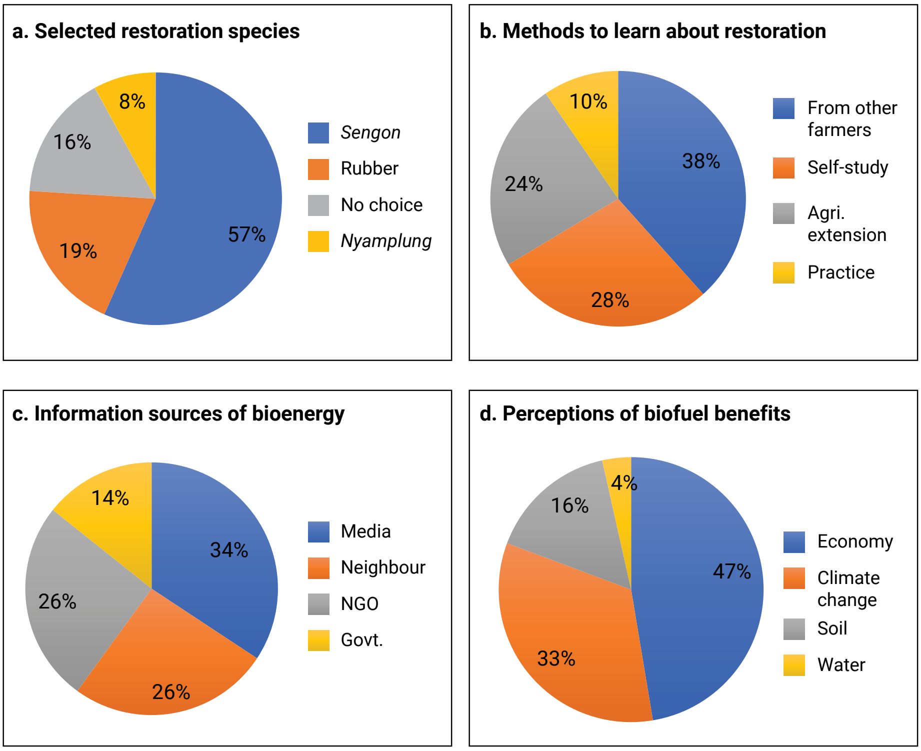


Figure 2. Landowner preferences for potential degraded land restoration species and perceptions of bioenergy

All variables of Model 1 achieved positive coefficients, except for the intercept, implying their positive marginal impacts on the landowners' preferences for *nyamplung* as a potential species for restoring degraded lands. These results showed that the chance—or likelihood ratio—for landowners to prefer *nyamplung* increased when they had a job in addition to farming (the "farming with another job" variable applied); they owned businesses providing additional income ("business income"); migrated from the Java region (or "Javanese"); they thought bioenergy supports climate change mitigation ("bioenergy benefit for climate"); they preferred agricultural extension for learning about species suited to degraded lands ("agricultural extension"); and/or they used river water ("river water use").

4.5 Discussion

Study results reveal lessons for bioenergy production from degraded land in Indonesia. Results of the logistic regression model and descriptive statistics of landowners imply three major lessons for building a bottom-up approach to bioenergy production from degraded land in Indonesia: (1) landowners require a stable bioenergy market; (2) bioenergy species should be familiar to landowners; and (3) landowners need capacity building support. Each of these is discussed below.

4.5.1 Landowners require a stable bioenergy market

The bioenergy market should be stable for landowners, as bioenergy production was mainly preferred by those landowners who could afford a market risk with bioenergy production, either because they had additional jobs ("farming with another job") or had other income sources ("business income") (Table 3). In other words, landowners felt bioenergy production still has market uncertainty, indicating a business risk. Thus, the opportunity to prefer bioenergy production was low for those landowners who relied solely on farming and had no other source of income, as they had limited capacity to cope with the risk associated with bioenergy production. This was corroborated by descriptive statistics showing most landowners (88%) did not prefer bioenergy production (Figure 2), as many of them (76%) had no additional jobs while only a few (15%) had additional incomes from business. This made them extremely wary of any market risks associated with farming (Table 2). The importance of a stable market is supported by other studies suggesting the lack of markets in which to sell bioenergy feedstocks was a major reason for the Energy Self-Sufficient Villages programme failing (Muslihudin et al. 2015), and that farmers involved in the programme preferred non-energy crops because they have stable markets (Fatimah 2015). Therefore, a stable market is a key requirement for a bottom-up approach to developing bioenergy production on degraded lands in Indonesia.

4.5.2 Bioenergy species should be familiar to landowners

Landowners would be more likely to participate in bioenergy production with species they are familiar with rather than species that are new to them. Results of the Firth logistic regression model showed landowners originally from Java being more likely than other ethnicities to opt for *nyamplung* (Table 3). Though *nyamplung* is new to Buntoi, it is prevalent in Java (Bustomi et al. 2018), so Javanese landowners now living in Buntoi would be more familiar with the species than other ethnic groups, which might have encouraged their selection of *nyamplung* as a restoration species for their degraded lands. This notion of familiarity influencing landowner preferences is supported by results showing *sengon* and rubber – species familiar to Buntoi villagers – being preferred choices for 76% of landowners for restoration of their degraded lands (Table 2), while indigenous ethnic Dayaks make up 77% of the population (Figure 2). Moreover, these results support literature suggesting landowners' traditions and cultures influence their decisions to cultivate bioenergy crops (Nurlaila et al. 2013; Sitompul et al. 2016). Therefore, using bioenergy species that are culturally familiar to landowners is important for developing a bottom-up approach to bioenergy production in Indonesia.

4.5.3 Landowners need capacity building support

Landowners who preferred bioenergy production indicated a need for agricultural extension support to build their technical capacity for cultivating bioenergy species (Table 3). A lack of capacity in landowners and limited technical guidance were major challenges for the energy self-sufficient villages programme (Muslihudin et al. 2015). Limited technical capacity would not only increase bioenergy production costs for landowners (Amir et al. 2008), but would also make production unreliable, thereby creating an unfavourable business environment for bioenergy refineries and companies (Fatimah 2015). Therefore, any bottom-up approach to bioenergy production should be able to support capacity building and provide agricultural extension for landowners in order to encourage participation in bioenergy production, ensure production costs remain efficient and stable, and reduce business risks for bioenergy refineries and companies.

4.5.4 Study limitations

We recognize this study has limitations, and acknowledge the need for further investigation. First, other factors such as knowledge of other bioenergy crops may well affect landowner preferences for bioenergy production. Second, this study does not discuss factors that may affect the preferences of other key stakeholders such as bioenergy refineries, companies and end consumers for bioenergy production on degraded land, even though these stakeholders would also play vital roles in establishing a bottom-up approach to bioenergy production. Third, while the study focused only on *nyamplung*, other potential bioenergy species in Indonesia include *Pongamia pinnata* (*malapari*), *Reutalis trisperma* (Blanco), Air Shaw (*kemiri sunan*) and *Calliandra calothyrsus* Meissner (calliandra) (Borchard et al. 2017), and as this study shows, different bioenergy species might generate different landowner preferences. Fourth, this study represents a case study of Buntoi Village in Central Kalimantan, whereas landowners in other areas with different socioeconomic and sociocultural conditions might hold different perceptions towards bioenergy production. Fifth, this study analyses only one type of degraded land; burned farmland, whereas landowner preferences for restoration species might differ for other types of degraded and/or abandoned land. These limitations indicate the need for future studies on a variety of factors with the potential to affect landowner preferences, on the preferences and interests of different stakeholder groups, on different bioenergy species and regimes in Indonesia, and on different types of degraded lands.

4.6 Conclusions

This study examined landowner perceptions towards bioenergy production by investigating factors affecting landowner preferences for bioenergy production on degraded lands in Central Kalimantan, Indonesia. Using Firth’s logistic regression model, we analysed responses from 150 owners of land degraded by fire in Buntoi Village. Results showed that most landowners (76%) preferred conventional species – *sengon* and rubber – for restoration of their degraded lands, while only a few (8%) preferred *nyamplung* for bioenergy production. Those opting for bioenergy production were characterized by their capacity to handle the market risk associated with bioenergy production because they had additional jobs and incomes, were Javanese farmers and landowners familiar with *nyamplung*, or preferred learning about restoration species through agricultural extension. Our results contribute empirically to identifying three key conditions for a bottom-up approach to bioenergy production on degraded land in Indonesia: a stable bioenergy market for landowners, the application of familiar bioenergy species, and extension support for capacity building. These conditions would serve as criteria for testing the feasibility of a bottom-up approach to bioenergy production. Further studies are required to test the feasibility of such an approach, including testing a variety of factors with the potential to affect landowner preferences, the interests of different stakeholders, diverse bioenergy species, and different types of degraded lands in Indonesia.

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CHAPTER 5

Potential energy yields of bioenergy crops in the tropics

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Abstract: Bioenergy can produce at least 25% of the global energy demand to combat climate change through reducing emissions in the energy sector. However, information on the bioenergy production potential of woody species and their suitability for silviculture on various soils in the humid tropics is limited. This slightly revised version of a short note published by Borchard et al. (2018) aims to identify tree species suitable for bioenergy production under these conditions. Data were compiled from 241 publications and nine freely available databases to assess environmental and silvicultural information on tropical tree species. Energy yield was derived from the estimated productivity of the reviewed species equivalent to an energy yield ranging between 2 and 444 GJ ha^{-1} yr^{-1}. As such, these bioenergy yields are within the range reported for the lignocellulosic biomass of energy crops cultivated in Europe, the USA and Brazil. Our review identified some high-yielding species (e.g., *Dyera polyphylla* (Miq.) Steenis, *Metroxylon sagu* (Rottb.), *Pongamia pinnata* (L.)) and leguminous species that could be beneficial in mixed stands (e.g., *Elaeis oleifera* (Kunth) and *Pongamia pinnata*) or are suitable species to grow on wet or re-wetted peatland (*Dyera polyphylla*). However, there are limitations to cultivating woody bioenergy species on wet peatland. Sustainable methods for managing and harvesting forests on wet or re-wetted peatland need to be developed.

Keywords: tropics, paludiculture, biomass, biofuel, biodiesel, bioethanol
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5.1 Introduction

It is predicted that global energy demand will increase substantially by 2040. Depending on the scenario, estimates range from 20% to 34% compared to consumption in 2018 (Newell et al. 2020), resulting in a massive CO_2 emission increase in case of neglecting renewable energy sources (IEA 2015). Evidently, achieving the 2°C limit on global warming requires new policies to reduce the energy sector's CO_2 emissions by replacing traditional and fossil fuels with renewable energies (Frei et al. 2013). Bioenergy, the energy produced from biological sources, is one such renewable energy (Brown and Feuvre 2017). Globally, bioenergy has the potential to produce 100–400 exajoules per year (EJ yr^{-1}) (Faaij 2006; Nijsen 2012), which is equivalent to 25%–100% of the total energy consumed in 2014 and 2017 (Brown and Feuvre 2017; IRENA 2017). According to Brown and Feuvre (2017), bioenergy from sustainable land use and forest management will be one of the most sustainable solutions among renewable energy options. Despite such enormous potential, in 2018, only around 1.9% of the electricity and 4.2% of the heat consumed were generated from biofuels (IEA 2021). Traditional use of biomass, although common in developing countries, remains inefficient and hazardous to health. However, bioenergy could provide clean and affordable energy to meet increasing demands in these countries (Faaij 2006; Balat M and Balat H 2009; IEA 2015). In the tropics, oil palm (*Elaeis guineenis* (Jacq.)) dominates biofuel production from tree species (Dislich et al. 2017; Proskurina et al. 2019). However, in comparison to forests, oil palm monoculture results in a loss of ecosystem functions (Dislich et al. 2017). This is less severe in mixed systems that may produce even higher yields per area (Zemp et al. 2019).

The aim of this study was to identify tropical tree species that could produce biological resources for bioenergy production and are able to grow on various types of soils. The potential biofuel and energy yields were estimated by assessing yields based on silvicultural information (e.g., stem density) and productivity (e.g., biomass per hectare per year), which were converted into energetic values (e.g., gigajoules per hectare per year (GJ ha^{-1} yr^{-1}). Due to the huge body of literature on species used and recommended for bioenergy production in the tropics, this study specifically focused on tree species for bioenergy production (Duke 1983; Biswas et al. 2011; Abel et al. 2013; Atabani et al. 2013).

5.2 Materials and methods

The aim of this narrative review (Uman 2011) was to identify tree species suitable for bioenergy systems in the tropics from the literature (Azam et al. 2005; Saito et al. 2005; Biswas et al. 2011; Abel et al. 2013; Atabani et al. 2013; Mekala et al. 2014) by combining their silvicultural information (Table 1) and potential energy yields per hectare per year (Table 2). A literature search using Google Scholar was conducted for silvicultural information using species names as keywords.

The search produced 241 documents and nine freely available databases (Borchard et al. 2018, Table S1). These were used to assess the following aspects of woody bioenergy crops: (i)

Table 1. Potential bioenergy species that tolerate unfavourable soil conditions

Soil conditions that are most relevant for species selection are presented. Potential ecological adaptations are also shown to inform about tolerances to, for instance, droughts and flooding. Primary data and their corresponding references are shown in Borchard et al. 2018.

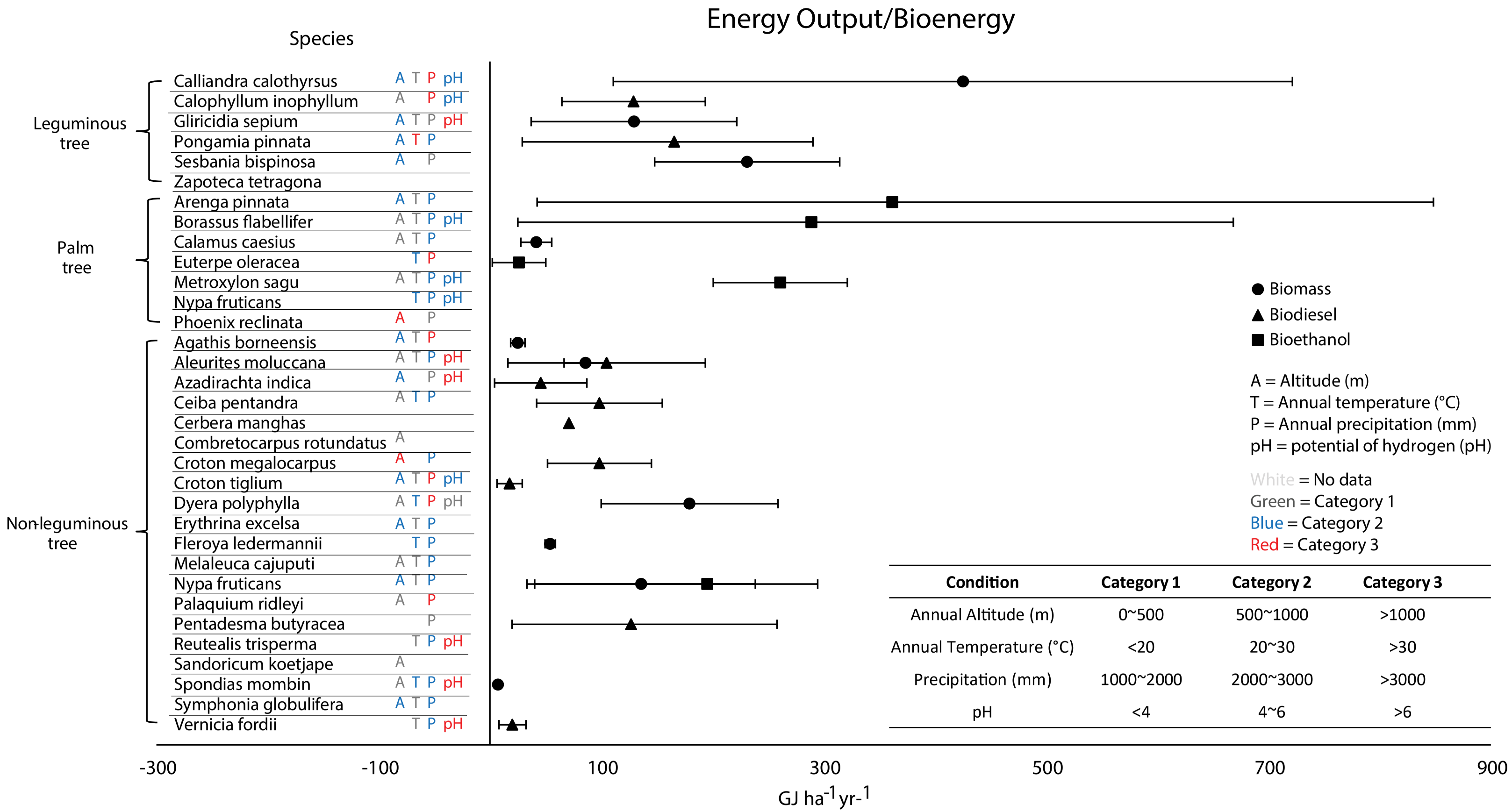
Species	Soil pH	Soil Texture	Soil Moisture	Soil Fertility	Additional Adaptations
Species that tolerate poor soils, moist and dry environments					
Agathis borneensis (Warb.)	<7	-/-	-/-	-/-	Deep, well-drained, acidic soil
Aleurites moluccana (L.)	5.0–8.0	-/-	Moist to dry	Poor	Tolerates droughts
Arenga pinnata (Wurmb.)	-/-	Sand	Moist to dry	-/-	Tolerates dry environments
Azadirachta indica (A. Juss.)	6.0–7.0	-/-	-/-	Poor	-/-
Borassus flabellifer (L.)	5.0–6.0	-/-	Moist to dry	-/-	Tolerates droughts and short-term flooding
Calliandra calothyrsus (Meisn.)	5.0–6.5	-/-	Moist to dry	Poor	Pioneer species, tolerates droughts
Calophyllum inophyllum (L.)	4.0–7.5	-/-	Moist to dry	-/-	Xerophytic species, tolerates droughts
Ceiba pentandra (L.)	-/-	Sandy	Moist	-/-	Deep, well-drained, light soil, Andosol
Croton megalocarpus (Hutch.)	-/-	Sandy	Moist	-/-	Pioneer species; deep, well-drained, light soil
Croton tiglium (L.)	4.5–7.5	-/-	-/-	-/-	-/-
Gliricidia sepium (Jacq.)	4.5–8.5	Various	Moist	-/-	Pioneer species, deep, well-drained soil
Neolamarckia cadamba (Roxb.)	-/-	-/-	Moist	-/-	Deep, alluvial soils
Pongamia pinnata (L.)	-/-	Sandy	Moist to dry	-/-	Deep soils, tolerates droughts and acidity
Reutealis trisperma (Blanco)	5.4–7.1	-/-	-/-	Poor	-/-
Vernicia fordii (Hemsl.)	6.0–6.5	Sandy	Moist to dry	-/-	Deep, well-drained, light soils
Zapoteca tetragona (Willd.)	-/-	-/-	-/-	-/-	-/-
Species that tolerate permanently wet and waterlogged or temporarily flooded soils					
Calamus caesius (Blume)	-/-	Peat, clayish, silty	Moist to wet	-/-	Margins of peat and swamp land, tolerates flooding
Cerbera manghas (L.)	-/-	-/-	Moist to wet	-/-	Riparian, swamp and mangrove environment
Combretocarpus rotundatus (Miq.)	3.0–4.5	Peat	Wet	-/-	Peat-swamp forest (*Shorea* spp.), tolerates waterlogged soils
Dyera polyphylla (Miq.)	3.0–4.5	Peat	Wet	-/-	Peat-swamp forest, wet soils, peat
Erythrina excelsa (Baker)	-/-	Various	Moist to wet	-/-	Riparian and swamp land, high water table
Euterpe oleracea (Mart.)	-/-	Sandy	Moist	-/-	Light soils, tolerates flooding
Melaleuca cajuputi (Powell)	-/-	Sandy	-/-	Poor	Poor, well-drained soils, brackish and acidic sulphate soils
Metroxylon sagu (Rottb.)	>4.5	Various	Moist to wet	-/-	Tolerates flooding
Fleroya ledermannii (K.Krause)	-/-	-/-	-/-	-/-	Anemochory, tolerates flooding
Nypa fruticans (Wurmb.)	5.0	Clayish	Moist to wet	-/-	Mangrove species
Palaquium ridleyi (King & Gamble)	3.0–4.5	Peat	Wet	-/-	Peat-swamp forest
Pentadesma butyracea (Sabine	-/-	-/-	-/-	-/-	Riparian forests, deep soils
Phoenix reclinata (Jacq.)	-/-	Various	-/-	-/-	Medium- to fine-textured soil, tolerates flooding
Sandoricum koetjape (Burm.f.)	≥7	Various	-/-	Poor	Pioneer species, riparian areas
Sesbania bispinosa (Jacq.)	<10	Various	Dry to wet	-/-	Alkaline soils, riparian areas, tolerates droughts
Spondias mombin (L.)	4.3–8.0	Various	-/-	-/-	Various mineral soils, tolerates flooding
Symphonia globulifera (L.f.)	-/-	-/-	Moist to wet	-/-	Lowland rainforest to swamp forest

Note: -/- no data available

botanical information (e.g., species and origin, synonyms, common name, typical use); (ii) ecological settings (e.g., temperature, mean annual precipitation, soil properties); and (iii) cropping and yields (e.g., stem density, biomass yield, bio-oil yield) (Borchard et al. 2018, Table S2). Data extracted from original resources were taken directly from the publication. Thus, our dataset represents original information without any conversion into a single system (e.g., FAO soil classification). Extracted soil pH values were mostly (i.e., 93%, Borchard et al. 2018, Table S2) published without further clarification on solutions used (e.g., H_2O, KCl, $CaCl_2$) or salt concentration, which affects the comparability of pH values (Edmeades and Wheeler 1990; Gavriloaiei 2012). Thus, due to the lower accuracy of pH values and ranges presented, this review can provide only approximate information on the soil pH values tolerated. Yield data in mass or volume per unit area were used as presented in surveys or calculations, based on single tree productivity (e.g., dry biomass, fruit yield, oil content) and stand density per unit area (Borchard et al. 2018, Table S2). Conversion factors used to derive energy yields (GJ ha^{-1} yr^{-1}) were: (i) carbon density of 0.5 in dry mass of wood (Penman et al. 2003); (ii) energy of 37 MJ stored per kg carbon or 19 MJ per kg dry biomass (German National Academy of Sciences Leopoldina 2012); (iii) a bio-oil – biodiesel conversion rate of 90% adapted from values published by Meher et al. (2006); (iv) biodiesel density of 0.9 g cm^{-3} (Meher et al. 2006; Hofstrand 2008); (v) energy of 33 MJ stored per litre of biodiesel (Meher et al. 2006; Hofstrand 2008); (vi) a sugar – bioethanol conversion rate of 51% (Demirbas 2005); (vii) bioethanol density of 0.8 g cm^{-3} (Hofstrand 2008); and (vii) energy of 21 MJ per litre of bioethanol (Hofstrand 2008).

5.3 Results

Although numerous woody species are suitable for forest-based bioenergy systems in humid tropical regions (Table 1), the estimation of potential bioenergy yields per unit of area (i.e., GJ ha^{-1} yr^{-1}) was limited to 33 species due to the scarcity of silvicultural and biorefinery data (Figure 1 and 2). This study provides species-specific information on environments preferred by each species, silvicultural information (e.g., stem density per hectare), and yield data (Mg dry biomass ha^{-1} yr^{-1}). Around 50% of the species ($n = 16$) are adapted to mineral soils and able to tolerate acidic and nutrient-poor soils (e.g., eroded Acrisols) and droughts (Table 1). Trees that can tolerate drought include *Aleuritis moluccana* (L.), *Calophyllum inophyllum* (L.) and *Pongamia pinnata.* Although their cropping on terrestrial soils potentially produces high yields, such yields will be reduced by flooding and wet soil conditions. In addition, soil wetness, soil acidity and low nutrient status may also limit plant productivity (Crosson 1997). In particular, biological nitrogen fixation by leguminous species that have been widely used to rehabilitate degraded land (e.g., *Calophyllum inophyllum*, *Gliricidia sepium* (Jacq.)) is drastically reduced in acidic soils. Based on tree productivity data and information on their silvicultural recommendations, species suitable for growth on mineral soils and (re)-wetted peatland (Table 1 and Table 2) can potentially produce between 0.2 Mg and 24.0 Mg biomass ha^{-1} yr^{-1}, 0.1 Mg and 9.0 Mg bio-oil ha^{-1} yr^{-1}, and between 0.2 Mg and approximately 20.0 Mg sugar ha^{-1} yr^{-1}, which is equal to an energy yield between 2 GJ and 444 GJ ha^{-1} yr^{-1} (Figure 1, Table 2).



Condition	Category 1	Category 2	Category 3
Annual Altitude (m)	0~500	500~1000	>1000
Annual Temperature (°C)	<20	20~30	>30
Precipitation (mm)	1000~2000	2000~3000	>3000
pH	<4	4~6	>6

Figure 1. Potential bioenergy yield per tree species expressed in GJ ha^{-1} yr^{-1}

Table 2. Potential annual biomass, bio-oil, sugar (Su), and starch (St) productivity in Mg ha^{-1} yr^{-1} of species used/potentially suitable for forest-based bioenergy production in tropical regions.

Biomass data were also converted into volumetric values (mL ha^{-1} yr^{-1}) and energy values (GJ ha^{-1} yr^{-1}). A 'Yes' indicates a promising species, but due to a lack of information in the literature, yield could not be estimated. Primary data and their corresponding references are shown in Borchard et al. 2018.

Species	**Biomass**		**Bio-oil and Biodiesel**			**Sugar or Starch and Bioethanol**		
	Mg ha^{-1} yr^{-1}	GJ ha^{-1} yr^{-1}	Mg ha^{-1} yr^{-1}	kL ha^{-1} yr^{-1}	GJ ha^{-1} yr^{-1}	Mg ha^{-1} yr^{-1}	kL ha^{-1} yr^{-1}	GJ ha^{-1} yr^{-1}
Species that tolerate poor soils, moist and dry environments								
Agathis borneensis (Warb.)	1.0–1.7	19–31	-/-	-/-	-/-	-/-	-/-	-/-
Aleurites moluccana (L.)	3.6–5.7	67–105	0.5–6.0	0.5–6.0	16–194	-/-	-/-	-/-
Arenga pinnata (Wurmb)	-/-	-/-	-/-	-/-	-/-	20 (Su)	2.0–12.8	43–268
Azadirachta indica (A.Juss.)	-/-	-/-	0.1–2.7	0.1–2.7	4–87	-/-	-/-	-/-
Borassus flabellifer (L.)	-/-	-/-	-/-	-/-	-/-	20 (Su)	1.2–12.8	25–268
Calliandra calothyrsus (Meisn.)	6.0–24.0	111–444	-/-	-/-	-/-	-/-	-/-	-/-
Calophyllum inophyllum (L.)	-/-	-/-	2.0–6.0	2.0–5.9	65–194	-/-	-/-	-/-
Ceiba pentandra (L.)	-/-	-/-	1.3–4.8	1.3–4.8	42–155	-/-	-/-	-/-
Croton megalocarpus (Hutch)	-/-	-/-	1.6–4.5	1.6–4.5	52–145	-/-	-/-	-/-
Croton tiglium (L.)	-/-	-/-	0.2–0.9	0.2–0.9	6–29	-/-	-/-	-/-
Gliricidia sepium (Jacq.)	2.0–12.0	37–222	-/-	-/-	-/-	-/-	-/-	-/-
Neolamarckia cadamba (Roxb.)	1.8–12.9	33–239	-/-	-/-	-/-	-/-	-/-	-/-
Pongamia pinnata (L.)	-/-	-/-	0.9–9.0	0.9–8.9	29–290	-/-	-/-	-/-
Reutealis trisperma (Blanco)	-/-	-/-	Yes	-/-	-/-	-/-	-/-	-/-
Vernicia fordii (Hemsl.)	-/-	-/-	0.3–1.0	0.2–1.0	8–32	-/-	-/-	-/-
Zapoteca tetragona (Willd.)	Yes	-/-	-/-	-/-	-/-	-/-	-/-	-/-
Species that tolerate continuously wet and waterlogged or temporarily flooded soils								
Calamus caesius (Blume)	1.5–3.0	28–56	-/-	-/-	-/-	-/-	-/-	-/-
Cerbera manghas (L.)	-/-	-/-	2.2	2.2	71	-/-	-/-	-/-
Combretocarpus rotundatus (Miq.)	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-
Dyera polyphylla (Miq.)	5.4–14.0	100–259	-/-	-/-	-/-	-/-	-/-	-/-
Erythrina excelsa (Baker)	Yes	-/-	-/-	-/-	-/-	-/-	-/-	-/-
Euterpe oleracea (Mart.)	-/-	-/-	-/-	-/-	-/-	0.2–3.8 (Su)	0.1 –2.4	2–50
Melaleuca cajuputi (Powell)	Yes	-/-	-/-	-/-	-/-	-/-	-/-	-/-
Metroxylon sagu (Rottb.)	-/-	-/-	-/-	-/-	-/-	15–24 (St)	9.6–15.3	201–321
Fleroya ledermannii (K.Krause)	2.7–3.2	49–59	-/-	-/-	-/-	-/-	-/-	-/-
Nypa fruticans (Wurmb.)	-/-	-/-	-/-	-/-	-/-	3–22 (Su)	1.9–14.0	40–295
Palaquium ridleyi (King & Gamble)	-/-	-/-	-/-	-/-	-/-	-/-	-/-	-/-
Pentadesma butyracea (Sabine)	-/-	-/-	0.6–8.0	0.6–7.9	20–258	-/-	-/-	-/-
Phoenix reclinata (Jacq.)	Yes	-/-	-/-	-/-	-/-	-/-	-/-	-/-
Sandoricum koetjape (Burm.f.)	-/-	-/-	-/-	-/-	-/-	Yes	-/-	-/-
Sesbania bispinosa (Jacq.)	8.0–17.0	148–315	-/-	-/-	-/-	-/-	-/-	-/-
Spondias mombin (L.)	0.2–0.6	4–10	-/-	-/-	-/-	-/-	-/-	-/-
Symphonia globulifera (L.f.)	Yes	-/-	-/-	-/-	-/-	-/-	-/-	-/-

Note: -/- no data available

Seventeen species are potentially suitable for bioenergy activities on wet land and land which is regularly flooded (Table 1). Three tree species tolerate brackish environments, namely *Cerbera manghas* (L.), *Nypa fructicans* (Wurmb.) and *Melaleuca cajuputi* (Powell). The energy yield potential of these species ranges between 71 GJ and 295 GJ ha^{-1} yr^{-1} (no data for *Melaleuca cajuputi*, Figure 1, Table 2). *Calamus caesius* (Blume) and *Symphonia globulifera* (L.f.) are adapted to wet soils rich in organic matter, while *Combretocarpus rotundatus* (Miq.) Danser*, Dyera polyphylla* and *Palaquium ridleyi* (King and Gamble) can grow on permanently wet organic soils (i.e., peatland). Although peatland species produce raw material for bioenergy activities, data on productivity and energy yields are rarely reported, with productivity data found only for *Dyera polyphylla* (Table 2). The remaining nine tree species presented in Table 2 tolerate flooding and produce biomass, bio-oil and sugar. Again, although information found on yields and productivity are minimal, the estimated energy output of some species may be too low for bioenergy activities (e.g., *Euterpe oleracea* (Mart.)*, Fleroya ledermannii* (K.Krause)*, Spondias mombin* (L.)), while the estimated productivity of *Pentadesma butyracea* Sabine and *Sesbania bispinosa* (Jacq.) seems to be promising for bioenergy activities (Table 2). Other species in this group are promising bioenergy crop candidates, but information on their productivity is not readily available (Table 2).

5.4 Discussion

The species presented that tolerate acidic soils and droughts are known and often used to produce raw material for bioenergy in tropical countries (Biswas et al. 2011; Atabani et al. 2013; Borchard 2017). However, initiatives that aim to produce bioenergy require silvicultural information and yield data. The information presented here can be used to assess the economic feasibility of bioenergy projects and cropping system types (Gruenewald et al. 2007; Ramachandran Nair et al. 2009; Vieira et al. 2009). Silvicultural and yield data are scarce for tropical tree species adapted to permanently wet and regularly flooded environments, but such data are required to develop feasible bioenergy strategies for wetlands (e.g., peatland). Two reasons could explain this knowledge gap: (i) limited interest in most of these tree species, except for sugar- and starch-producing palm trees (*Metroxylon sagu, Nypa fructicans*); and (ii) a lack of machinery for harvesting (Wichtmann et al. 2016). To avoid competition between food production and the production of raw materials for bioenergy, non-food crops should be cultivated on less productive land (e.g., eroded soil) (Balat M and Balat H 2009; German National Academy of Sciences Leopoldina 2012; Borchard et al. 2017).

The simplest approach to rehabilitating eroded land is the establishment of plantations (Chazdon 2003). Optimizing initial plant growth on eroded land for biomass production may require the application of fertilizer, which can cause the emission of N_2O (Popp et al. 2011; German National Academy of Sciences Leopoldina 2012). A less-assessed, but promising, way to reduce the amount of N-fertilizer is to mix non-leguminous and leguminous crops (e.g., *Elaeis oleifera* (Kunth) Cortés and *Pongamia pinnata*). Rehabilitation may require initial site preparation by planting species that can shade out weeds, fix nitrogen and improve soil organic matter (Chazdon 2003). Trees suitable for site preparation are fast-growing, nitrogen-fixing species, e.g., *Calliandra calothyrsus* (Meisn.), *Gliricidia sepium*, and *Zapoteca tetragona* (Willd.). The cultivation of non-native tree species risks invasive competition (Ziller and Howard 2008; Chimera et al. 2010; Richardson and Blanchard 2011). Thus, introducing for example species native to Africa (i.e., *Croton megalocarpus* (Hutch)) and America (i.e., *Spondias mombin*) to Southeast Asia and could have negative impacts on biodiversity and environmental services.

The rehabilitation of wetlands requires the selection of species that can tolerate wet soils and are adapted to natural conditions of peat swamp forests (e.g., *Dyera polyphylla*) (Wichtmann et al. 2016), yet there is limited information available on suitable trees for peat-swamp rehabilitation activities. In this study, bioenergy yields are compared to those of palm oil trees (*Elaeis guineenis*), which produce 3 Mg–6 Mg bio-oil ha^{-1} yr^{-1} (Wahid et al. 2005; Wicke et al. 2008; Verheye 2010), equivalent to an energy output of 90 GJ–194 GJ ha^{-1}. Most of the assessed species have the potential to produce raw material (*Palaquium ridleyi*, *Sandoricum koetjape* (Burm.f.)) generating the same level of energy. For some species, very high yields have been reported (e.g., *Dyera polyphylla*, *Metroxylon sagu*, *Pongamia pinnata*) (Azam et al. 2005; Manuri et al. 2016; Tata et al. 2017), potentially far above yields that are possible on degraded land. Other species with an estimated energy output of <90 GJ ha^{-1} yr^{-1} (i.e., the lowest energy output estimated for *Elaeis oleifera*) might not be feasible for bioenergy activities in tropical countries.

5.5 Conclusions

Tree species adapted to tropical wetlands and peatlands are potentially useful for bioenergy production, but published data are available only for a small number of species. The estimated bioenergy yields of the reviewed woody species are in the range reported for lignocellulosic biomass of energy crops cultivated in Europe, the USA and Brazil (110 GJ–370 GJ ha^{-1} yr^{-1}) (Faaij 2006; German National Academy of Sciences Leopoldina 2012). However, the values and coefficients used to estimate energy yields per unit area may fail to reflect the real variability of caloric values of biomass from various species (Demirbaş 1997; Günther et al. 2012). Thus, this study provides initial estimations, which should be verified by experiments to test the impact of silviculture and biorefinery methods on energy yields.

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CHAPTER 6

Potential benefits of integrated bioenergy and food production systems on degraded land in Wonogiri, Indonesia

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Abstract: Cultivating suitable biofuel crops on degraded land by involving local communities can be a promising solution for energy and food security while restoring land. This chapter provides information on the socioeconomic and environmental benefits of *Calophyllum inophyllum* L., known locally as *nyamplung*, based on agroforestry systems practiced by local farmers in Wonogiri District, Central Java Province, Indonesia. Relevant information was gathered through field observations and a focus group discussion with 20 farmers practicing "*nyamplung*-based agroforestry systems" with rice, maize, peanuts and honey. The net present values (NPVs) of rice and peanuts indicated negative profitability when they were grown as monocultures, whereas maize generated only marginal profits. Amazingly, honey production utilizing *nyamplung* produced an NPV nearly 300 times higher than maize. However, combined with *nyamplung*, honey was also the commodity most sensitive to decreases in production, followed by *nyamplung*–peanut and *nyamplung*–rice combinations. While decreases in production had little effect on the NPVs of rice, peanuts and maize, these annual crops can only be cultivated for a maximum of six years within *nyamplung*'s 35-year production cycle, due to canopy closure after this time. In conclusion, *nyamplung*-based agroforestry systems can provide economic, social and environmental benefits on different scales. Additionally, considering the high profit potential of combining *nyamplung* with honey production, it is necessary to improve and develop bee husbandry practices to make doing so a viable option for local farmers.

Key words: Land restoration, *nyamplung*, local crops, benefits
Link: https://www.cifor.org/knowledge/publication/7164/
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6.1 Introduction

Landscapes provide valuable environmental goods and services to humankind, from income sources to goods for consumption, like food, fodder, fuelwood, timber and water (Lawrence and Vandecar 2015). However, human land-use practices, particularly agriculture expansion, also lead to land degradation and a reduction of these valuable environmental services (Alcamo et al. 2005; Millennium Ecosystem Assessment 2005; Babigumira et al. 2014). This poses a serious challenge when aiming to end hunger and poverty, conserve biodiversity and adapt to climate change (Sunderland et al. 2007; Fleskens and Stringer 2014). Given the finite amount of productive land available, how to ensure the well-being of our expanding population – projected to reach close to ten billion by 2050 – without depleting the resource base and destroying ecosystems, is a pressing question (Sunderland 2011; UN 2017). In this context, restoration of degraded lands provides an opportunity to increase the global resource base for sustainable production of food and commodities, while addressing current and future global challenges. Several recent initiatives, such as the Bonn Challenge, the New York Declaration on Forests, and the SDG target on Land Degradation Neutrality, have emerged and targeted global land restoration efforts (i.e., 2,500 million hectares) and intend to avoid targeted area overlap with good coordination (FAO 2015a, 2015b).

Land degradation is more acute in tropical countries like Indonesia. Faced with a growing population and rapid economic development, Indonesian landscapes are under considerable pressure. In recent years, the Government of Indonesia (GoI) has made significant progress in addressing deforestation and forest degradation issues (World Bank 2016). It has initiated a national programme to restore degraded land throughout the country (Budiman et al. 2020), and taken corrective action through policies on forest fire prevention and management; a moratorium on issuing new licences on primary forest and peatlands; and sustainable forest management certification and timber legality assurance systems.

Restoration of degraded land through afforestation, reforestation, agroforestation, natural regeneration and climate-smart agriculture provides an opportunity to reverse biodiversity loss and enhance the delivery of ecosystem services (Roshetko et al. 2007; Chazdon et al. 2016; Rahman et al. 2017). However, it is important to recognize that each landscape is unique, and restoration efforts should consider the underlying cause of degradation, as well as the socioeconomic and ecological demands on the landscape (Rahman et al. 2017). Successful land restoration depends not only on the rehabilitation of biodiversity and the ecosystem, but also on the choice of appropriate species, and their suitability in the landscape, so that local people's needs can also be fulfilled (Lamb et al. 2005; Paudyal et al. 2017; Borchard et al. 2018; Maimunah et al. 2018). Equally, for a landscape to be sustainable, production of food and energy must coexist alongside biodiversity (Tilman et al. 2009). Research shows perennial bioenergy crops could be planted on degraded or marginal lands that could otherwise be costly to restore (Tilman et al. 2006; Baral and Lee 2016). As governments and international organizations join the global effort to restore degraded lands, integrating bioenergy crops into such efforts provides opportunities to address both the social and economic challenges of restoration.

Being able to meet the high costs involved in land restoration in Indonesia – approximately USD 398 to USD 12,153 per hectare, depending on the condition of land and costs related to restoration methods (Table 1) – affects whether people managing agricultural and forest landscapes embrace such restoration efforts (Strassburg and Latawiec 2014; Brown 2017). With this in mind, bioenergy species like *nyamplung* (*Calophyllum inophyllum* L.) have potential for use as restoration crops in agroforestry systems, offering a climate-smart farming approach by producing bioenergy as well as playing a role in soil and biodiversity conservation (Prabakaran and Britto 2012; Baral and Lee 2016; Schweier et al. 2017; Borchard et al. 2018; Jaung et al. 2018; Maimunah et al. 2018). As such farming can bring environmental and socioeconomic benefits without sacrificing agricultural production, it might prove a viable way to shift toward sustainable production and scale back unsustainable agricultural practices that may lead to further degradation and deforestation (Boucher et al. 2011; Brown et al. 2013; Rahman et al. 2017). Improving access to affordable and reliable forms of energy, and enhanced and diverse food production, is essential to reduce poverty, eradicate hunger and promote economic growth in the developing world (Malla 2013; Rahman 2017; Rahman et al. 2017).

This research assesses the socioeconomic and environmental benefits of bioenergy within *nyamplung*-based agroforestry crop systems in Wonogiri District in Central Java Province, Indonesia. *Nyamplung*'s potential as a perennial crop for smallholder farmers has been recognized in Indonesia, the Philippines and India since more than twenty years ago (Roshetko and Evans 1999; Gunasena and Roshetko 2000; Uripno et al. 2014; Khamidah and Darmawan 2018), but limited research and few development activities have been conducted with the species.

Table 1. Land restoration costs in Indonesia by degradation stage and restoration approach[1]

Degradation Stage	Restoration method	Estimated costs (USD ha^{-1})[2]
Stage 1 (least degraded)	Protection	398
Stage 2 (somewhat degraded)	Assisted natural regeneration	844
	Assisted natural regeneration (Castilo 1986)	3,489
Stage 3 (fairly degraded)	Framework Species Method	2,537
Stage 4 (most degraded)	Maximum diversity with mine site amelioration	10,890
	Miyawaki method	12,153

Notes:

1 Based on this table the average cost of land restoration in Indonesia is USD 5,000 per hectare (see Baral et al. 2019)
2 Based on 2018 prices

Source: Baral et al. 2019

6.2 Materials and methods

The study area is located in Wonogiri District in Central Java Province, Indonesia (Figure 1), which lies between 7°42'43.56"S and 8°12'42.79"S latitude. With its equatorial climate, it has average precipitation of 1,878 mm, and temperatures between 20°C and 38°C. The total area of Central Java is 3.25 million ha, of which 0.73 million ha (22.26%) is degraded (ICCC 2014; BPS 2018). The study area was previously managed by state-owned forestry company Perhutani, but is now considered an unproductive degraded area of state-owned land due to its lack of soil nutrition (N = 0.04%–0.07%, P = 1.80–4.07 ppm, and K = 0.11–0.13 me per 100 g) (Hasnah and Windyarini 2015; Leksono et al. 2015).

During our focus group discussion (FGD), respondents said local household incomes were mainly being derived from crop production, cattle rearing and remittances from family members working in cities. Agriculture in the area mainly involved rainfed-based (November–March) subsistence practices adopted by small-scale farmers. Based on our FGD and field observations, two major land-use systems were being practiced in the study area: monocultures of rice, maize and peanuts; and agroforestry (intercropping of rice, maize and peanuts with *nyamplung* for seed production). In total, fifteen farmers were practicing *nyamplung*-based agroforestry. Food crops were also planted on government managed land, using the government's 'forest estate lease' mechanism for farmers. Some farmers were also practicing beekeeping in *nyamplung* agroforestry areas for honey production.

The site was selected in order to produce the required research data (i.e., socioeconomic and environmental benefits of *nyamplung*-based agroforestry systems). It was essential for the degraded areas to have farmers cultivating a variety of crops (e.g., monocultures of rice, maize and peanuts) alongside *nyamplung* for their livelihood necessities. This type of cultivation allowed their potential to be investigated with precision. The sustainability of livelihoods in the study area, like many other regions with degraded land in Indonesia, is threatened by poverty and low incomes (BPS 2013). Moreover, the legal restrictions on harvesting some products (e.g., timber) from natural forest provide an economic incentive for smallholders to integrate their farming systems. All of these characteristics in the study area are representative of a large proportion of Indonesian and tropical Asian agricultural landscapes.

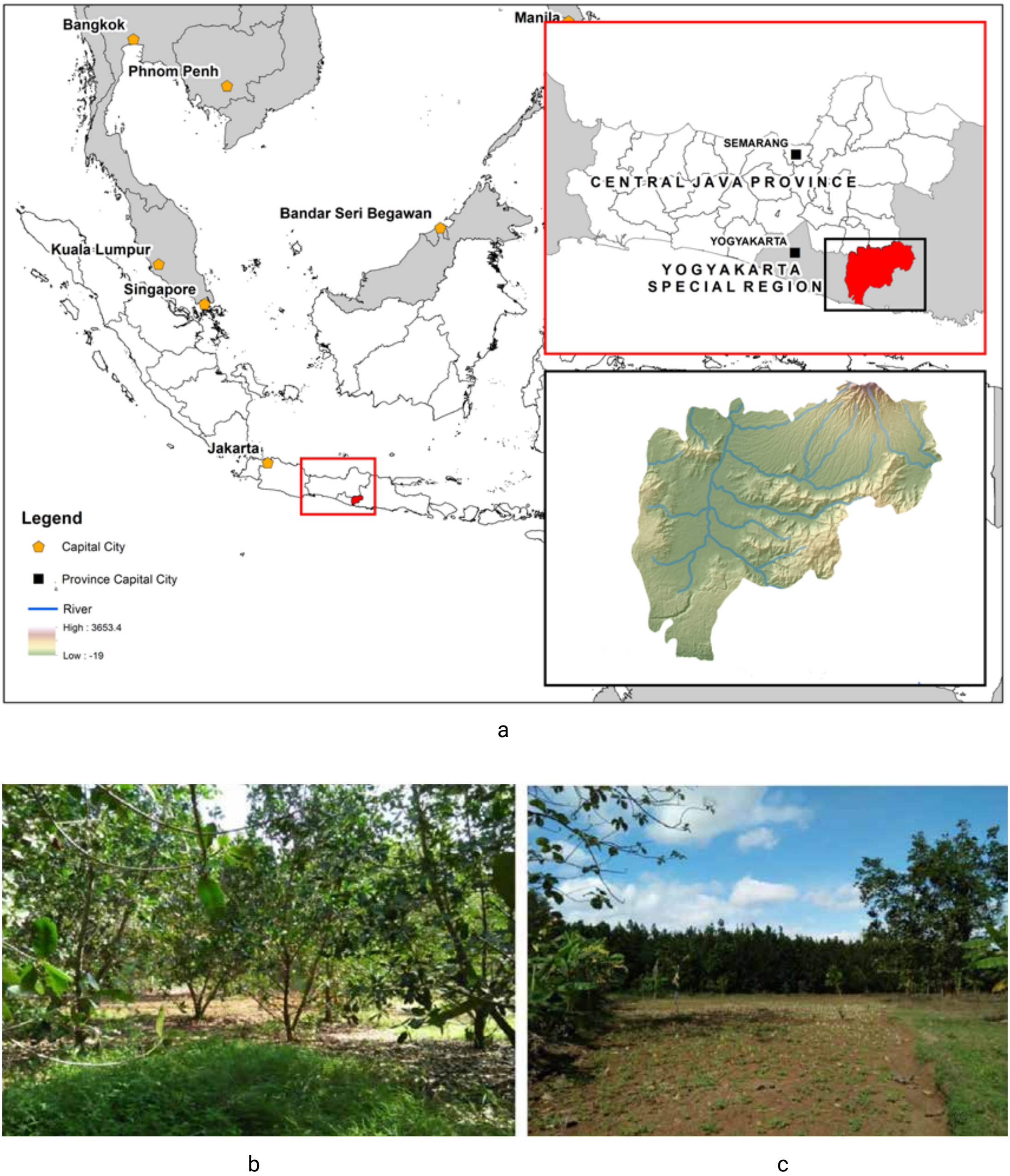

Figure 1. Study site: (a) Wonogiri District, Central Java, Indonesia; (b) local *nyamplung*-based agroforestry system; and (c) peanut monoculture.

Source: Map and photographs ©2017 CIFOR

6.2.1 Data collection and analysis

A focus group discussion (FGD) and field observations were used to collect primary data on the various local farming systems presented in this study. Twenty local farmers (10 practicing *nyamplung*-based agroforestry and 10 practicing monocultures) attended the FGD session. Farmers in the FGD were purposively selected based on their good knowledge of local farming systems (i.e., the range of crops cultivated in the area, cultivation seasons, cultivation methods, production input and output costs, market values, socioeconomic and environmental potential of cultivation, and farmer motivation), and the socioeconomic and geographic states of the village and its surroundings. A set of key FGD questions was prepared to guide the session. The FGD questions were clearly explained to the participants so they could fully understand each issue covered. A report was prepared immediately after the session to summarize the answers and opinions given by the participants as well as to check their validity. Lastly, the summarized information was verified by the participants.

Field observations were conducted in two farming locations selected based on information gathered in the FGD. During observations, several pictures of local farming systems (i.e., *nyamplung*-based agroforestry and monocultures) were taken, and relevant farming information was noted. Secondary data was gathered from the Southeast Asian regional office of ICRAF and CIFOR's headquarters, both located in Bogor, West Java, to corroborate the primary data collected from the study area and check their reliability, and to provide background information and qualitative inputs for the study.

Using a narrative analysis technique, qualitative analysis of the social and environmental potential of agroforestry systems was conducted based on the data collected from the FGD and field observations. Quantitative analysis, that is, net present value (NPV), was used to assess the overall economic performance of local farming systems over a 35-year and 6-year time period with a 10% discount rate. A sensitivity analysis was also conducted on variation in understory crop yields where *nyamplung* was intercropped, as combinations of diverse species might affect understory crop production (Elevitch and Wilkinson 2000; Rahman et al. 2016; Rahman et al. 2017).

6.3 Results and discussion

NPV was calculated for monocultures of four popular farmed commodities: maize, rice, peanuts and honey, and for *nyamplung* (Figure 2). Rice and peanut monocultures led to negative profitability while maize only provided marginal profits (NPV of IDR 3 million) compared to those generated from *nyamplung* seed harvests (NPV of IDR 87.1 million) and from honey production (NPV of IDR 854.6 million) utilizing *nyamplung*. The commodity yielding the greatest profits was honey, with an NPV nearly ten times higher than that of *nyamplung* alone, and 300 times higher than maize grown as a monoculture.

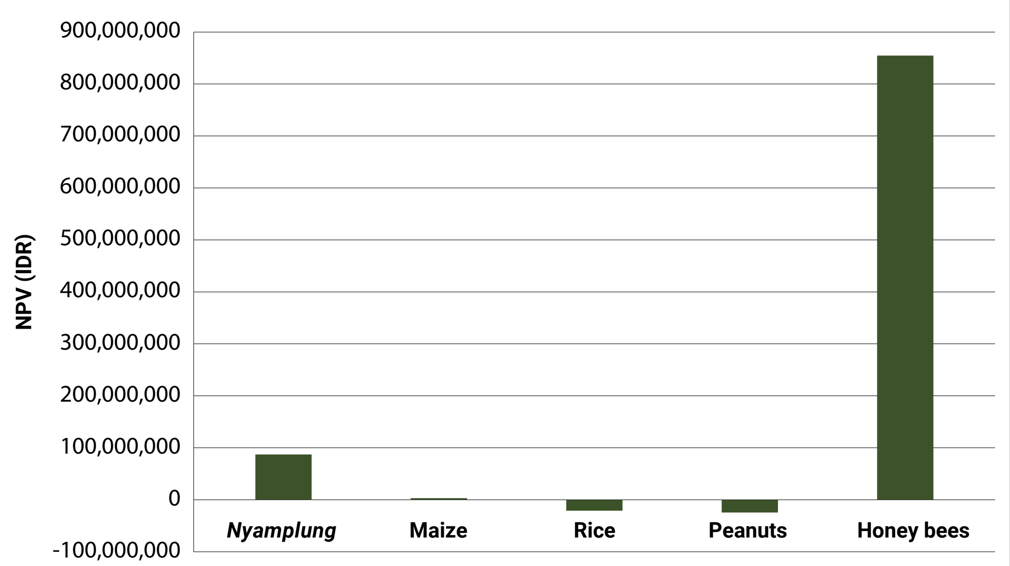

Figure 2. NPVs of five popular commodity monocultures in Wonogiri over a 35-year rotation period

Despite negative profitability, farmers in Wonogiri cultivate peanuts and rice for their subsistence and food security value. Rice is considered a staple food, with peanut leaves used as fodder for cattle production. Maize is used as both a staple food and livestock feed. During the FGD, farmers stated that producing rice and peanuts was more affordable than purchasing those commodities in local markets.

As profits from *nyamplung* seeds could compensate for losses from rice and peanut cultivation, our analysis suggests that cultivating *nyamplung* with rice and peanuts might be financially preferable (i.e., NPVs of IDR 66.2 million and IDR 62.6 million, respectively), while intercropping with maize could generate extra profits (NPV of IDR 90.1 million) (Table 2).

Also, *Nyamplung* grown in combination with honey production could generate the highest profits (NPV of IDR 941.7 million). Even with losses of as much as 60% as a result of crop failure caused by pests and diseases, climate change etc., this agroforestry system could still generate a positive NPV, and therefore be financially viable. Similar cultivation modelling on combinations of tree crops and seasonal crops by Rahman et al. (2016) have also shown improved economic performance (NPV) in their research sites in West Java and eastern Bangladesh.

However, over the full cycle, the economic return of each individual crop grown with *nyamplung* would vary. Maize and rice could only be grown for the first six years of the 35-year cycle as *nyamplung* canopy closure thereafter would prevent such shade-intolerant crops from growing in the understory. Peanut production would follow a similar trend, and even in an optimistic scenario, its production could only continue until year eight of the cycle.

Table 2. Sensitivity of overall profitability (NPV in millions IDR ha^{-1}) to decreases in production of *nyamplung* and four understory crops counted over a 35-year time horizon

Decrease in Production	*Nyamplung*	*Nyamplung* + integrated crop			
		Maize	Rice	Peanuts	Honey
0%	87.1	90.1	66.2	62.6	941.7
10%	74.8	89.8	64.1	60.1	856.2
20%	62.4	89.5	62.0	57.7	770.8
30%	50.1	89.2	60.0	55.2	685.3
40%	37.8	88.9	57.8	52.8	599.9
50%	25.4	88.6	55.8	50.3	514.4
60%	13.1	88.3	53.7	47.8	428.9

More shade-tolerant crop alternatives, such as ginger and turmeric, have been widely integrated into agroforestry systems across Indonesia (Rahman et al. 2016; Riyandoko et al. 2016). However, due to poor soil conditions, these crops are not commonly cultivated in Wonogiri. Considering the decrease in yields when intercropped with *nyamplung*, maize resulted in the smallest loss (Figure 3; Table 2). Yet, even if maize production were decreased by half, its NPV would decrease by only 1.64% over the same time.

In comparison, *nyamplung* as a single crop and honey production with *nyamplung* (*nyamplung* + honey) were heavily sensitive to changes in yield. If the yields of *nyamplung* and *nyamplung* + honey were decreased by 60%, the resulting incomes (NPVs) would decrease by 85.0% and 54.5%, respectively. However, honey production would be possible from the sixth to the thirty-fifth year, unlike understory crops which could only be cultivated at the starting phase of the system when *nyamplung* trees are young. As the NPV of honey production would likely increase as *nyamplung* trees matured and produced more nectar, this particular system of integration could be a highly desirable and beneficial investment option for Wonogiri's farmers.

As honey has a longer production life and higher income prospects than other commodities as described in the earlier section of this paper, any crop combination model with honey could have better income prospects. Therefore, even though our analysis of cultivation models was based on data collected from the study area, farmers could cultivate more complex systems, such as 'rice + maize + *nyamplung* + honey'; 'rice + peanuts + *nyamplung* + honey'; or 'maize + peanuts + *nyamplung* + honey', based on their livelihood objectives. Although honey production could provide higher income prospects in Wonogiri, very little literature mentions honeybee management in Central Java, particularly in relation to how bees interact with *nyamplung* trees. Additionally, the extent to which honeybees are sensitive to external pressures and shocks, such as climate change, which has already adversely impacted insect pollinators in Europe and the Middle East (Carreck 2016), has not been identified clearly. Honey production has been practiced in Indonesia for years, but de Jong (2000) stated that the way in which bee collectors handle production differed greatly between regions. More research is needed for developing better bee husbandry

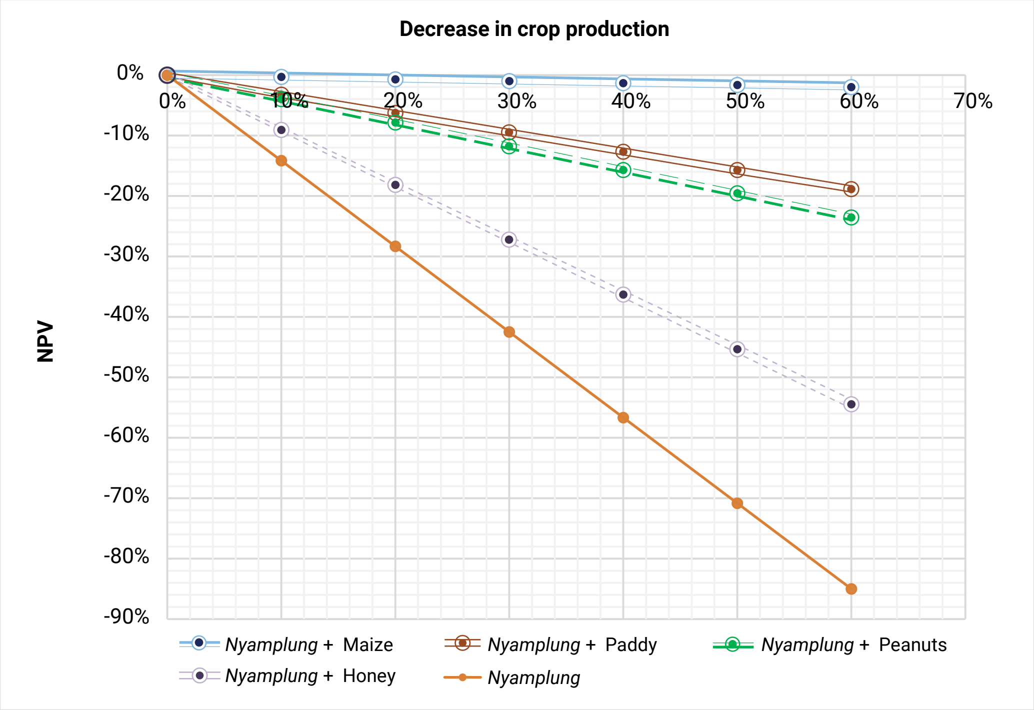

Figure 3. Proportional loss (%) of NPV with decreasing rates of production counted over a 35-year time horizon

practices, and so this could become a feasible option for local farmers. Regardless of honey production techniques and bee husbandry practices, a diversified agroforestry system would help to buffer against external shocks and pressures.

Nyamplung is already being cultivated by some farmers in the Wonogiri study area and shows viability for wider adoption. This is because, as our results demonstrate, there are good financial prospects for farmers to establish *nyamplung*-based cultivation systems on marginal lands, and help restore them (Artati et al. 2019).

As staple crops, rice, maize and peanuts have special livelihood and food security values for farmers, despite showing apparently negative (i.e., rice, peanuts) or marginally positive (i.e., maize) NPVs. Farmers might lack confidence and feel more exposed to higher market prices when buying rather than cultivating these commodities, and might be afraid of losing their cultural identity if they were to give up cultivating such specific traditional crops (Mwase et al. 2015; Rahman et al. 2016). They could bear such losses by gaining higher income from *nyamplung* and associated products (i.e., honey) which would enable them to purchase food and other necessities. Thus, in a wider sense, farmers' decisions to adopt *nyamplung*-based agroforestry systems could be based on considerations for tradition as well as the trade-offs between lower and higher income prospects.

Our research not only identified *nyamplung*-based systems as being economically viable, but also demonstrated that *nyamplung* cultivation strengthens social solidarity, with farmers sharing tree-planting knowledge. Farmers cultivating *nyamplung* were valued in the community, as involvement in such combined cultivation was considered more prestigious than growing rice or maize monocultures.

Nyamplung-based systems would also create employment opportunities for traders, and seasonal/regular-wage labourers, who could work harvesting, sorting and transporting farm products. Thus, such systems could support the emergence of farm-related rural employment and expertise. From a social and institutional perspective, as well as creating jobs and being a symbol of prestige and cultural identity, agroforestry in Indonesia can be critically important in strengthening social cohesion (Michon 2005; Rahman et al. 2017).

Information from FGD participants and field observations demonstrated that *nyamplung* cultivation in our study area had already improved overall biodiversity and environmental quality, providing bird habitat and fresh air, as well as controlling soil erosion and protecting crops from wind damage, with the increased numbers of trees on degraded land.

Nyamplung production in our study area performed well even on low-fertility soils. This observation supports the perception that bioenergy crops might have low nutritional demands and maintenance requirements, and thus are suitable for marginal lands (Butterbach-Bahl and Kiese 2013; Dillen et al. 2013; Schweier et al. 2017). Baral and Lee (2016) argued that careful utilization of degraded lands to produce bioenergy crops, such as *nyamplung*, could avoid negative impacts on food production and associated land degradation. As fossil fuel-based energy is unsustainable and causes greenhouse gas (GHG) emissions, bioenergy could be a viable alternative to address future societies' green and sustainable energy needs.

Nyamplung is also useful as a firebreak, as it shades out fire-prone grasses, and is moderately tolerant to fire. This special species is also resistant to typhoons. The species is also useful in soil stabilization, as well as playing a role as a windbreak in coastal areas (Prabakaran and Britto 2012), which could help reduce erosion and protect crops. It could also support ecotourism as a landscape ornamental plant (Lim 2012; Atabani and Cesar 2014). Therefore, a properly designed bioenergy production system could contribute to the achievement of several objectives, such as increasing sustainable energy access, mitigating climate change and providing rural employment (Casillas and Kammen 2010).

Furthermore, as the Government of Indonesia set biodiesel blending rates of 20% in 2016 and 30% in 2020 for public and private use through Minister of Energy and Mineral Resources Regulation No. 12/2015[7] and Presidential Decree No. 61/2015 (Kharina et al. 2016), it has significantly increased the importance of domestic biofuel production. These policies have opened an opportunity to utilize and govern the use of degraded land for biofuel production without interfering with existing agriculture and forest land, and to save millions of square kilometres of such land from biofuel production and its possible associated threats (Mooney 2018). However, there might be a need for follow-up regulations on monitoring the long-term restoration of degraded and marginal lands for sustainable biodiesel production, and preventing the clearance of forested land for biodiesel crop plantations.

6.4 Conclusion

In agroforestry systems, intercropping *nyamplung* with various annual crops, or using it in association with honey production, provides farmers in Wonogiri with viable economic options at different scales. Most notably, this study shows that although monocultures of rice and peanut are not profitable (having negative NPVs), growing these commodities could become financially viable when combined with *nyamplung* production, due to the high value *nyamplung* holds as a bioenergy crop. Honey production is the most profitable practice in local agroforestry systems, and despite honey production with *nyamplung* having the highest percentage of NPV loss when production decreased, it would still generate the highest profits. In addition to their income prospects, as *nyamplung*-based agroforestry systems contribute to social solidarity and create employment, such cultivation is prestigious for local farmers, so they could contribute to making viable use of and restoring degraded lands in Central Java. As *nyamplung* is already being cultivated in the study region, there is a positive likelihood of farmers adopting these systems.

Nevertheless, effective implementation strategies must be adopted for such systems to become sustainable, possibly because farmers' financial resources and human capital may be restricted. For *nyamplung*-based agroforestry systems to have long-term environmental benefits, they must also remain socioeconomically favourable for local farmers in the long run. Further research is necessary for developing better bee husbandry, in order to ensure honey production with *nyamplung* can become a guaranteed viable option for local farmers. This challenge can be seen as a positive opportunity for improving local farmers' engagement, which could be achieved through supporting policies.

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CHAPTER 7

Suitability of bioenergy tree species on degraded peatlands in Central Kalimantan, Indonesia

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Trifosa Iin Simamora, Sarah Andini, Soo Min Lee and Himlal Baral

Abstract: Vast areas of degraded peatlands in Kalimantan need a sustainable long-term restoration mechanism, ideally one that can address energy security without compromising food production or biodiversity conversation. This research assesses the survivability and growth performance of potential bioenergy crops: *gamal* (*Gliricidia sepium* (Jacq.) Walp.), *kaliandra* (*Calliandra calothyrsus Meissner*), *kemiri sunan* (*Reutealis trisperma* (Blanco) Airy Shaw) and *nyamplung* (*Calophyllum inophyllum* L.), that could be cultivated to produce bioenergy and restore degraded peatlands. Parameters observed were tree height and stem diameter growth as well as plant survival rates. Trials was conducted on a two-hectare demonstration plot on burned degraded peatland in Buntoi Village, Pulang Pisau District, Central Kalimantan Province. Using a split plot design, two treatments were applied to each species, i.e., agroforestry (intercropped with *Ananas comosus* (L.) Merr.) and monoculture plantation. For each species, these treatments were replicated in two separate subplots. Results indicate *nyamplung* being the most adaptable species, followed by *kemiri sunan*, and both species performing better under agroforestry than monoculture treatments. Further study is needed to assess productivity and associated biofuel yields.

Keywords: bioenergy, agroforestry, peatland restoration
Link: https://www.cifor.org/knowledge/publication/7033/
This is an edited version of an article previously published in *Land* (Maimunah et al. 2019).

7.1 Introduction

Due to population growth, urbanization and economic development, Indonesia's demand for bioenergy has increased significantly (IEA 2015), with depleting fossil fuel sources unable to meet increasing energy demands into the future (Firdaus et al. 2015). Whilst responding to interests in renewable energy and degraded land restoration, bioenergy can provide a potential alternative to meet growing energy demand. The Government of Indonesia has mandated to increase renewable energy production, including bioenergy, with the aim of renewables making up 23% of the national energy mix by 2025 (GoI 2014). However, expansion of bioenergy production could trigger competition with other land uses, such as food production and biodiversity conservation. To avoid such competition, degraded land has been identified as a potential target for bioenergy production (Nijsen et al. 2012). Central Kalimantan Province has a significant area of degraded land, estimated at approximately 7.2 million hectares (ha) (ICCC 2014). Forest conversion for other land uses, such as agriculture and open pit mining, is a key factor driving land degradation (Suwarno 2016). Frequent forest fire occurrence, particularly in recent years, has driven an escalation in degraded land, including degraded peatlands (Page et al. 2002). Fires have affected agricultural land managed by local farmers, causing productivity to fall, resulting in most burned land, including peatland, being abandoned due to its reduced fertility (Carlson et al. 2013).

Central Kalimantan is also facing energy deficits, with 42% of households in the province having no access to electricity (GGGI 2015). Consumption of biomass in traditional cooking practices is relatively high (IRENA 2017). To increase community access to energy, the central government, through the Ministry of Energy and Mineral Resources (ESDM), in collaboration with district and provincial governments, has initiated a bioenergy programme called Bioenergi Lestari. The programme involves planting bioenergy crops on approximately 62,500 ha of abandoned land, including degraded land in Pulang Pisau and Katingan districts, with the expectation of increasing bioenergy production (Rony 2015). However, very few studies provide useful information on bioenergy crops suitable for growing on degraded lands in Central Kalimantan. To fill this knowledge gap, this research project aimed to identify the most adaptable bioenergy crops suitable for degraded lands, and gauge their performance in agroforestry and monoculture systems.

As large areas, particularly peatlands, affected by deforestation and forest degradation need a viable long-term solution for restoration linked to energy security and producing renewable energy, the performance of bioenergy crops in restoring peatlands needed to be tested. This research aimed to assess the performance of potential bioenergy crops, and their potential for restoring burned and degraded peatlands without compromising food security.

7.2 Materials and methods

Buntoi Village, located between 02°48’59.4” S and 114°10’47.3” E in the district of Pulang Pisau in Central Kalimantan, Indonesia (Figure 1) was selected as the study site. Buntoi, with a total land area of 16,261.595 ha, is dominated by forest and agricultural land (Figure 2). Its soils are predominantly peat and alluvial. The village has a humid tropical climate with temperatures ranging from 26.5 to 27.5°C. The Ministry of Energy and Mineral Resources and the local government has chosen Buntoi Village as one of a number of locations under the Bioenergi Lestari project.

Buntoi has a total population of 2,729, most of whom depend on farming and rubber and *sengon* (*Albizia chinensis*) plantations (Buntoi Village Government 2017). In late 2015, Buntoi Village was badly affected by forest and peat fires, which destroyed large areas of farmers’ productive land, including approximately 461 ha of rubber plantations. The burned land has since been abandoned, and farmers are now looking for alternative land uses to meet their livelihood needs.

Trials were conducted between March 2016 and February 2017 on two hectares of degraded peatland. Having a total of 16 subplots, a split plot design was applied to test the performance of four potential biofuel species under two different treatments: monoculture and agroforestry with a system involving intercropping with pineapple. The two-hectare total area of the plots limited the number of possible replications to only two.

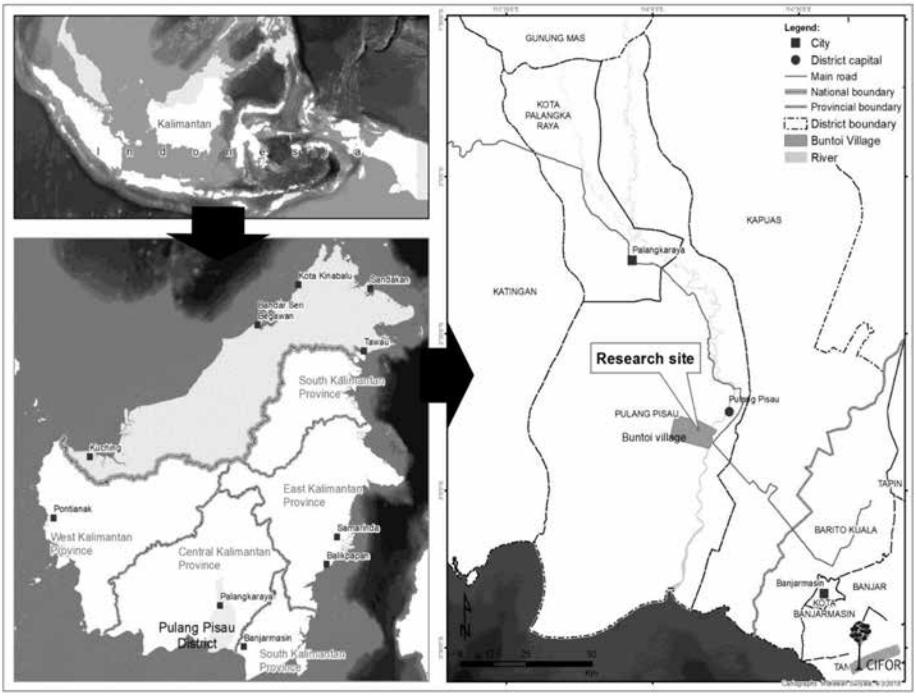

Figure 1. Location of Buntoi Village in Central Kalimantan Province, Indonesia

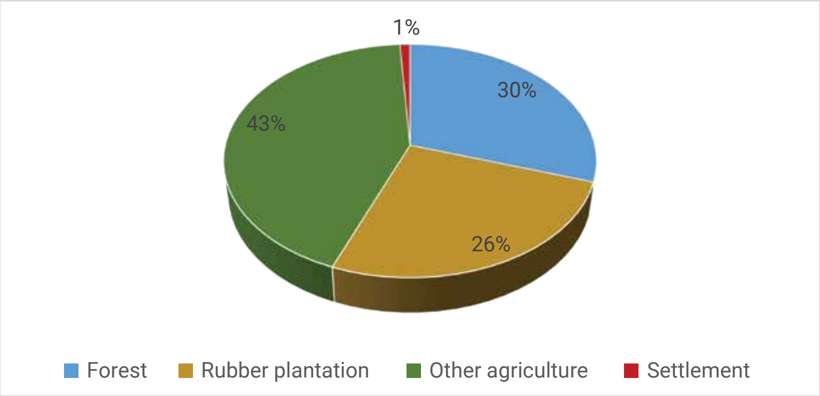

Figure 2. Land uses in Buntoi Village

Four species: *Gamal* (*Gliricidia sepium*), *kaliandra* (*Calliandra calothyrsus*), *kemiri sunan* (*Reutealis trisperma*) and *nyamplung* (*Calophyllum inophyllum*) were selected to test their capacity to adapt to extreme environmental conditions in degraded peatlands. Previous studies had suggested that *nyamplung* is adaptable to waterlogged areas (Leksono et al. 2014), *kaliandra* is tolerant to acidic soils of pH 4–5 (Palmer et al. 1995), *kemiri sunan* is adaptable to marginal land (Perry et al. 2013) and *gamal* is tolerant to acidic soils (Bhattacharya 2003) (Table 1.).

Parameters observed in our study included tree height (cm) and stem diameter (mm) measured from 10 cm above ground level. Survival rates were also observed by counting the total number of saplings surviving in each plot. Data were recorded on a monthly basis using the above parameters. As the research site was a fire-prone area, to ensure the safety of the trial plots we used a six-metre firebreak to separate the plots from natural vegetation and four-metre firebreaks to separate them from rubber trees and a road. We also used six-metre breaks between the different treatment plots. In terms of plant spacing, the different species were spaced as follows: *kaliandra* and *gamal* (2 m x 1 m), *kemiri sunan* and *nyamplung* (8 m x 8 m) and pineapple (*Ananas comosus*) (1 m x 1 m).

Table 1. Adaptability of selected bioenergy crops

No.	Species	Type of biomass	Adaptation capability	References
1	*Kaliandra*	wood	Acidic soil (pH 4.9–5.3) and drought	Leksono et al. 2014; Vijay et al. 2016
2	*Nyamplung*	seed	Saline soil and waterlogged areas	Abram at al. 2017; Gaveau et al. 2016
3	*Malapari* (*Pongamia pinnata*)	seed	Saline soil and waterlogged areas	Arun et al. 2017; Mainoo and Ulzen-Appiah 1996
4	*Kemiri sunan*	seed	Areas with slope gradient of 15%–40%	Perry et al. 2013; Zi et al. 2012
5	*Gamal*	wood	Acidic soil (pH < 5.5)	Ong et al. 2011; Orwa et al. 2009

Peatland depth profiles and pH values were also measured from four sample points in the trial plots by measuring their distance from a river, i.e., two samples taken 50 m from the river and two samples taken 200 m from the river. In addition to descriptive statistics, the results of non-parametric Kruskal-Wallis tests and post-hoc results of Wilcoxon rank-sum tests in R software (version 3.4.4) were used to analyse the data.

7.3 Results and discussion

Peatland depth and pH values in the study plots ranged from 56 cm to 87 cm and from 2.88 to 3.19, respectively (Table 2). These showed that with a medium acidity level, peatland depth was relatively thicker in proximity to the river. The survival rates of energy crops shown in Figure 3 suggest that with survival rates of 88% and 48% respectively, *nyamplung* and *kemiri sunan* are adaptable to degraded peatlands. *Kaliandra* and *gamal*, however, were unable to survive in our trial plots. We may conclude, therefore, that only *nyamplung* and *kemiri sunan* are viable options for planting on burned degraded peatlands.

Table 2. Peat depth profile and pH values in the trial plots

Sample no.	Distance from river (m)	pH value	Peat depth (cm)
1	50	2.88	85.00
2	50	2.95	87.00
3	200	2.81	77.00
4	200	3.19	56.00

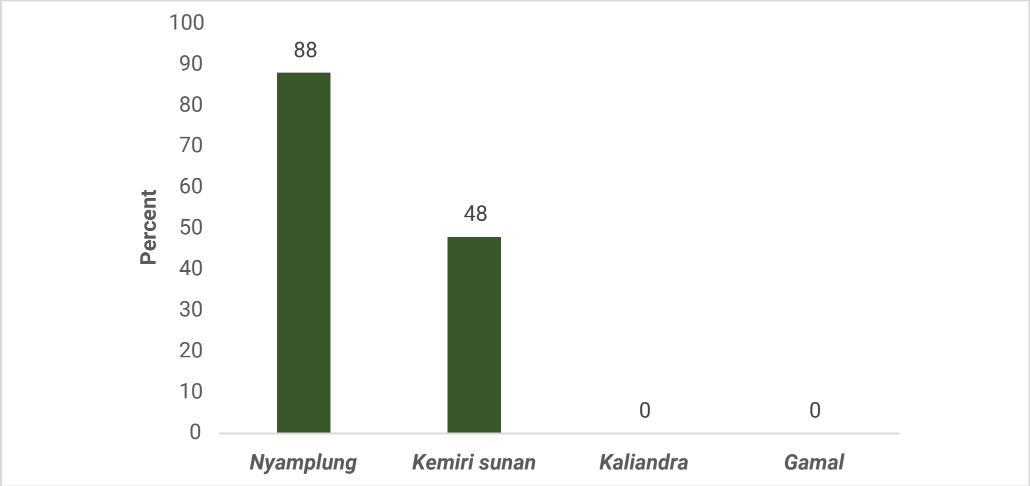

Figure 3. Survival rates of the four selected bioenergy species

Figures 4 and 5 show the growth rates in study plots for *nyamplung* and *kemiri sunan*; the two trialled species adaptable to degraded land. Growth rates for *nyamplung* were steady in all conditions except agroforestry plot B, where the growth rate was comparatively high for months five and six, after which it became steady. Growth rates for *kemiri sunan* remained steady under all conditions except monoculture plot B, where the growth rate for the first and last month was comparatively high. Higher growth rates for these months may have been due to external input and weather condition factors, i.e., fertilizer application and rainfall/sunlight, respectively. The figures also indicate that both species experienced better growth rates with intercropping than under monocultures. Nevertheless, further investigation is necessary to determine which external factors affect growth. Our data also illustrates stem diameter growth increasing steadily for both *nyamplung* and *kemiri sunan* under intercropping and monoculture systems (Figures 6 and 7).

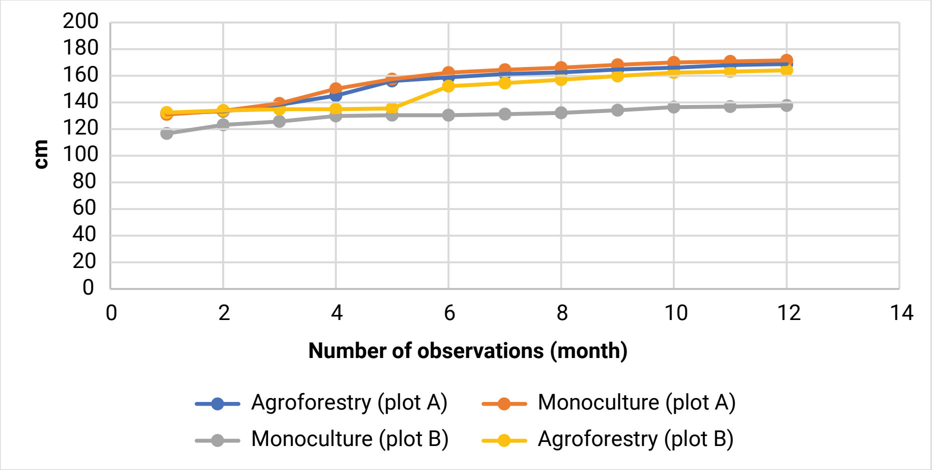

Figure 4. Tree height growth for *nyamplung*

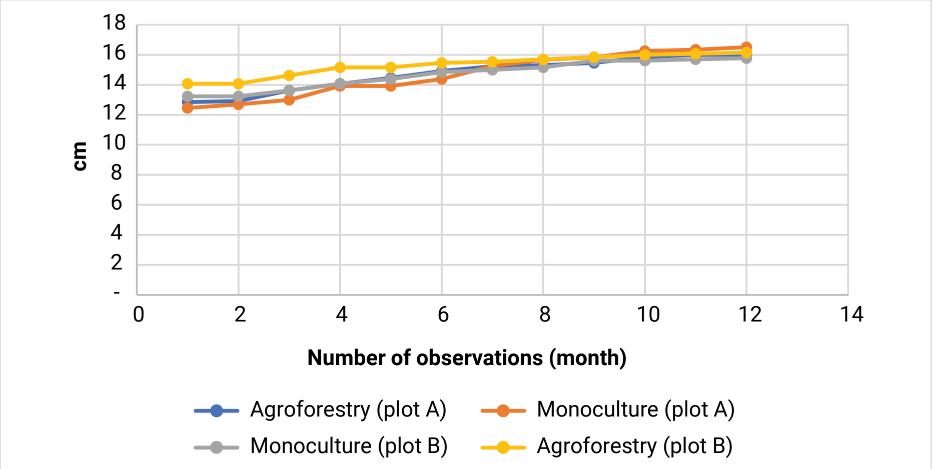

Figure 5. Tree height growth for *kemiri sunan*

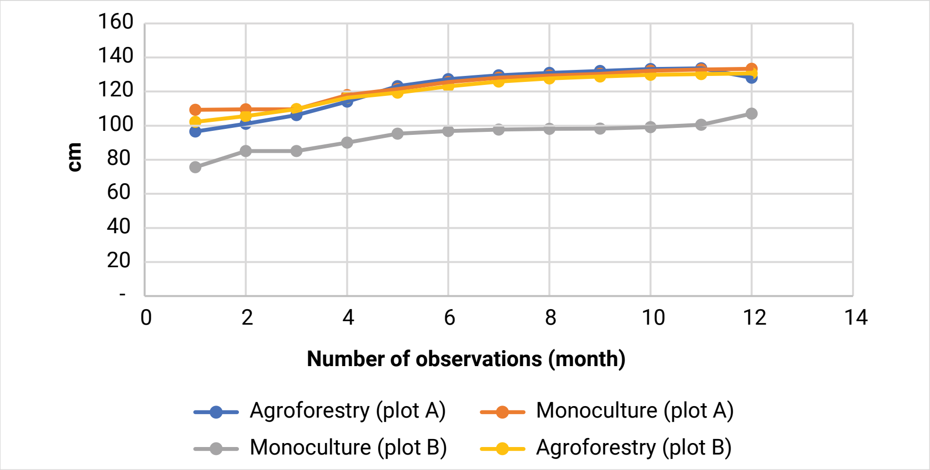

Figure 6. Stem diameter growth for *nyamplung*

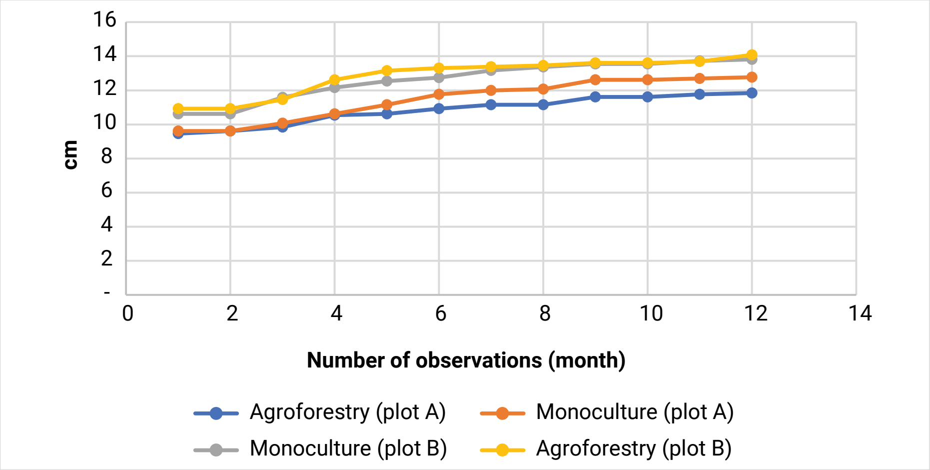

Figure 7. Stem diameter growth for *kemiri sunan*

Our Wilcoxon rank-sum tests further showed *nyamplung* performing better than *kemiri sunan* for both tree height and stem diameter growth (Figures 8 and 9). Both species performed better for tree height growth under agroforestry than monoculture treatments (Figure 10). However, only *nyamplung* performed well for stem diameter growth under agroforestry conditions (Figure 11).

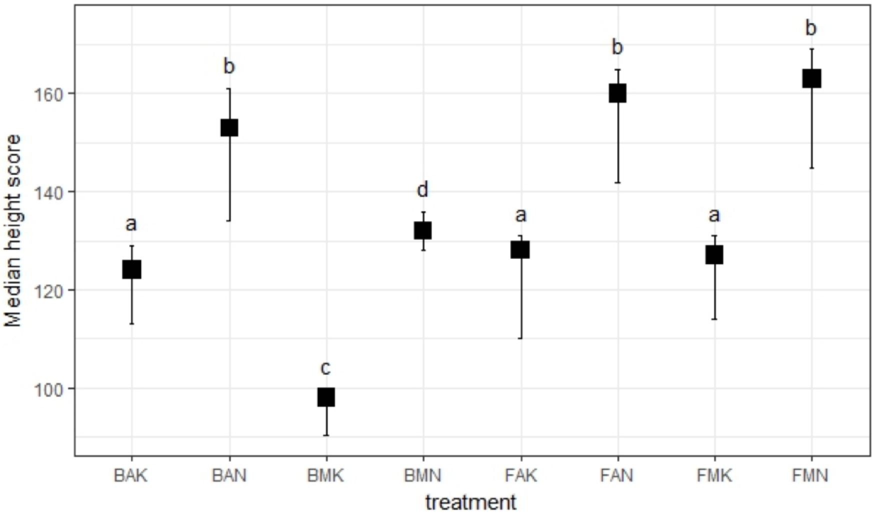

Figure 8. Results of Wilcoxon rank-sum tests on tree height for *nyamplung* and *kemiri sunan*

Notes: BAK = *kemiri sunan* agroforestry plot B; BAN = *nyamplung* agroforestry plot B; BMK = *kemiri sunan* monoculture plot B; BMN = *nyamplung* monoculture plot B; FAK = *kemiri sunan* agroforestry plot A; FAN = *nyamplung* agroforestry plot A; FMK = *kemiri sunan* monoculture plot A; and FMN = *nyamplung* monoculture plot A). Letters a, b, c and d show different tree height performance levels.

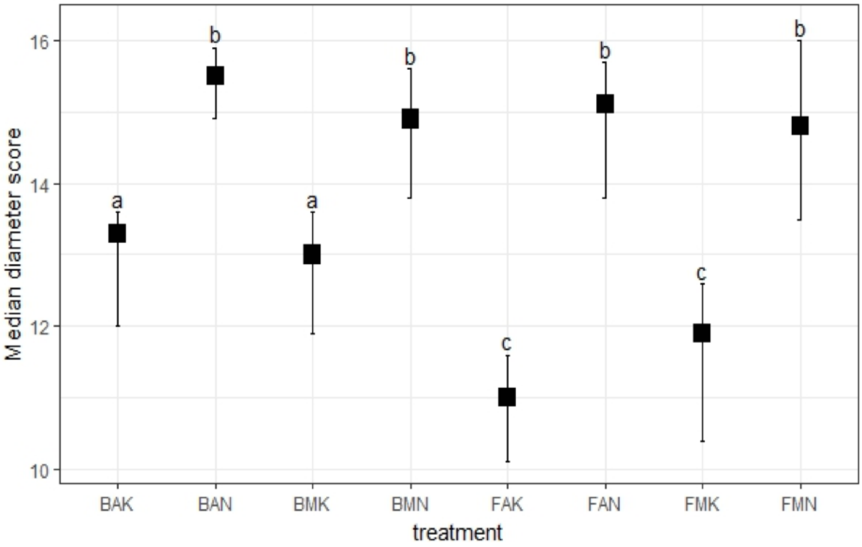

Figure 9. Results of Wilcoxon rank-sum tests on stem diameter for *nyamplung* and *kemiri sunan*

Notes: BAK = *kemiri sunan* agroforestry plot B; BAN = *nyamplung* agroforestry plot B; BMK = *kemiri sunan* monoculture plot B; BMN = *nyamplung* monoculture plot B; FAK = *kemiri sunan* agroforestry plot A; FAN = *nyamplung* agroforestry plot A; FMK = *kemiri sunan* monoculture plot A; and FMN = *nyamplung* monoculture plot A). Letters a, b and c show different stem diameter performance levels.

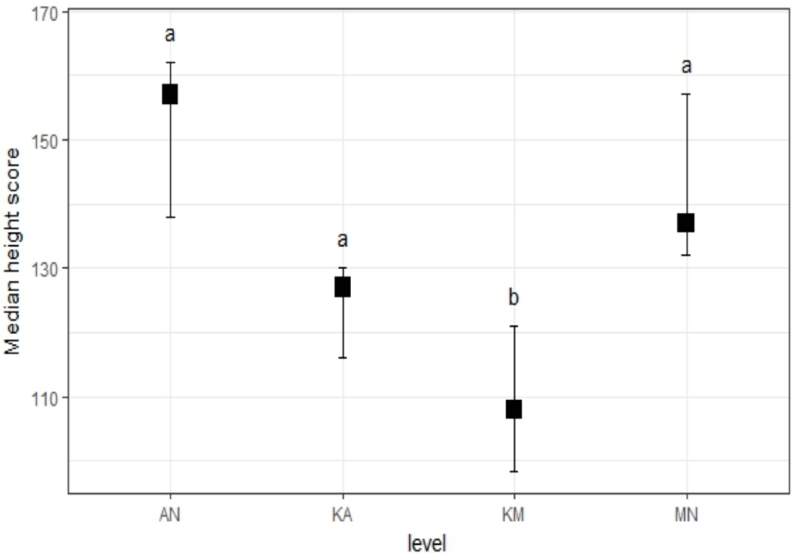

Figure 10. Results of Wilcoxon rank-sum tests on tree height under agroforestry and monoculture treatments for *nyamplung* and *kemiri sunan*

Notes: AN = *nyamplung* agroforestry; KA = *kemiri sunan* agroforestry; KM = *kemiri sunan* monoculture; and MN = *nyamplung* monoculture). Letters a and b show different tree height performance levels.

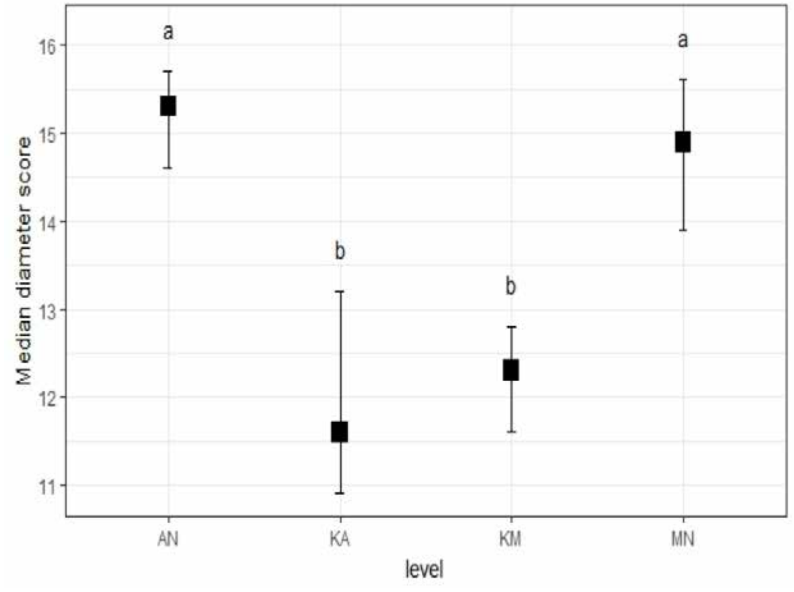

Figure 11. Results of Wilcoxon rank-sum tests on stem diameter under agroforestry and monoculture treatments for *nyamplung* and *kemiri sunan*

Notes: AN = *nyamplung* agroforestry; KA = *kemiri sunan* agroforestry; KM = *kemiri sunan* monoculture; and MN = *nyamplung* monoculture). Letters a and b show different stem diameter performance levels.

Our research shows *nyamplung* to be the species most adaptable to burned and degraded peatlands in Central Kalimantan, followed by *kemiri sunan*. Both species performed more favourably under agroforestry than monoculture treatments. This appears to be a win-win solution, as growing biofuel under agroforestry systems can be a better land-use strategy, considering the potential to enhance farm production and incomes, protect biodiversity and support sustainable development (Dagar et al. 2014). If the target is to motivate local farmers to use their degraded land for biofuel production, it is essential to consider that tree growing by farmers is often associated with multiple objectives influenced by livelihood necessities and local cultures (Rahman et al. 2008). Current literature emphasizes farmers' capacity to adopt tree planting being dependent on production technology, adequate physical infrastructure and developed markets for tree products (Shuren and Snelder 2008). Improved understanding of these circumstances is crucial for policy improvements to succeed in making tree planting feasible, acceptable and ultimately profitable for local people and related stakeholders (Franzel and Scherr 2002).

Planting millions of square kilometres of biofuel plantations could sequestrate huge amounts of carbon annually while also providing adequate energy stock (Mooney 2018). Supportive policies could further assist biofuel production on degraded land to avoid compromising agricultural production and to avert negative environmental consequences.

7.4 Conclusion

This study demonstrates that with survival rates of 88% and 48%, respectively, *nyamplung* and *kemiri sunan* were the most suitable of the four trialled bioenergy producing species for cultivation on degraded peatlands in Central Kalimantan. Neither *gamal* nor *kaliandra* appear to be viable options as none of the planted saplings survived. Growth performance indicators show that *nyamplung* grew better in agroforestry than monoculture treatment plots, in terms of both tree height and stem diameter. Similarly, *kemiri sunan* performed better in terms of tree height growth in agroforestry plots. This awareness of *nyamplung* and *kemiri sunan*'s capacity to survive on degraded peatlands and their improved performance under agroforestry systems can help promote the benefits of agroforestry and enhance farmers' livelihoods in addition to supporting sustainable development. Nevertheless, further studies are necessary on the production performance of both species to supplement the data.

Further studies are also needed to trial different species on different degraded peatlands. These should include more accurate extended measurement variables, such as soil nutrients, peat water table and peat depth. Selecting tree species with multiple benefits in terms of livelihoods, local culture familiarity and strong market value, may be beneficial for improving farmers' motivation to utilize degraded lands for biofuel production.

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CHAPTER 8

Comparison of soil microfauna diversity between a burnt and unburnt peatland in Indonesia

Seongmin Shin, Kishor Prasad Bhatta, Novi Sari Wahyuni, Yusuf B Samsudin, Yustina Artati and Himlal Baral

Abstract: Approximately 95 percent of peatlands in Indonesia have been degraded by forest fires or converted for cultivation. Forest fires release huge volumes of carbon dioxide into the atmosphere and have caused severe damage to Indonesia's ecosystems and biodiversity, particularly in Kalimantan and Sumatra. Even though understanding post-fire environmental dynamics and biodiversity changes would be highly beneficial in determining restoration processes, baseline analyses on biodiversity and soil moisture content in burnt and degraded peatlands remain limited. Consequently, this research explores and assesses soil macrofauna diversity and properties, and changes in soil fauna patterns in a burnt peatland area currently undergoing restoration with the establishment of a bioenergy plantation in Buntoi Village, Central Kalimantan Province, Indonesia. Results from the study site show peatland fires causing hugely reduced numbers of soil mesofauna and macrofauna individuals, and bioenergy tree survival rates being higher in plots on unburnt than burnt peatland. Fauna species diversity, gauged using the Shannon diversity index (*H*), was lower in burnt than unburnt areas, though some orders – such as Hymenoptera – appear to adapt well to burned areas as we found them in both burnt and unburnt plots. Results show a significant correlation between peat fires and biodiversity. We also found that the more seriously fire damaged bioenergy trees were, the higher the likelihood of biodiversity decreasing. Generally, soil moisture and nutrient availability are key factors supporting higher soil invertebrate diversity in unburnt areas. However, results showed no significant correlation between soil moisture content and soil fauna diversity in our research site. In conclusion, understanding the severe impacts of fire on peatlands will make people more aware and less likely to use fire for clearing and preparing peatlands, thereby prolonging their use.

Keywords: forest fire, biodiversity, soil fauna, bioenergy, soil moisture, restoration

8.1 Introduction

Tropical peatlands play a significant role in global ecosystem dynamics by providing ecological, social and climate benefits (Harrison et al. 2019). Around 50–70% of the world's wetland areas are peatlands, which cover a total area of approximately 38 million hectares (ha). Many of these peatlands (14.9 million ha) are located in Indonesia, with provinces in Sumatra and Kalimantan having the highest proportions of peatlands at 34–43% and 28–32%, respectively (BBPPSDLP 2011). Southeast Asia's peatlands are recognized globally as reservoirs of biodiversity (Posa et al. 2011).

However, peatlands have undergone drastic transformations and been critically degraded by forest fires and land conversion. Forest fires are a key driver of peatland deforestation and degradation, release huge volumes of carbon dioxide into the atmosphere and have caused severe damage to Indonesia's ecosystems and biodiversity, particularly in Kalimantan and Sumatra (Saharjo 2016). Severe peat fires on drained peatlands converted for cultivation in Indonesia have caused serious environmental and economic damage both locally and globally (Carmenta et al. 2017). Peat forests in Indonesia were degraded at a rate of around 2.6% per year between 2007 and 2015 (Miettinen et al. 2016), and only 4,000 km^2 (7.4%) of Kalimantan's 57,000 km^2 of peatlands remained in pristine condition in 2015 (Miettinen et al. 2016). More than 90 percent of Indonesia's peat swamp forests have been devastated or degraded (FAO 2012), accounting for the largest proportion of degradation among all forest types (Budiharta et al. 2014).

Fires in forests and peatlands disturb and dry out soil, adversely affecting micro- and macro-organism populations and diversity. In forests and peatlands, soil biodiversity is essential and critical for improving and supporting soil quality (Barrow 1991; Saharjo and Nurhayati 2006; Suciatmih 2006; FAO 2008; Saharjo et al. 2011), ecological functions and ecosystem services (Anderson 1975; Usher et al. 1979; Giller 1996). Following a peatland fire, soil fauna require a significant length of time to recover, but also contribute to soil recovery and fertility, and improved properties and condition (Wasis et al. 2018) as they have both direct and indirect effects on nutrient cycling and litter decomposition (Winsome 2005). Even though understanding post-fire environmental dynamics and biodiversity changes would be highly beneficial in determining restoration processes, baseline analyses on biodiversity and soil moisture content in burnt and degraded peatlands remain limited.

This research aimed to identify soil macrofauna diversity in a peatland area restored with bioenergy trees in Buntoi Village, Central Kalimantan Province, Indonesia, and compare this diversity in burnt and unburnt peatland areas. Environmental indicators relating to soil properties were also assessed and compared between the burnt and unburnt peatlands. An objective was to establish baselines for faunal diversity, soil biology and change in pre- and post-fire peatlands restored with bioenergy trees.

8.2 Materials and methods

8.1.1 Study area

Kalimantan and Sumatra in Indonesia, which form parts of the Sundaland biodiversity hotspot (Myers et al. 2000), are estimated to host up to 15,000 flowering plant, 37 endemic bird, and 44 mammal species (MacKinnon et al. 1996). IUCN (International Union for Conservation of Nature) has classified 415 of the regions' species as threatened. The research site in Buntoi Village, Central Kalimantan Province is located at 2° 048' 059.4" S and 114° 010' 47.3" E (Figure 1) and has a humid tropical climate (BVG 2014). Larges areas of forest and peatlands in Buntoi Village were severely degraded as a result of fires in 2015. Since then, the Center for International Forestry Research (CIFOR) has established the area as one of the most important pilot project sites for planting bioenergy crops as a means for peatland restoration. In February 2016, CIFOR established two hectares of trial plots for the bioenergy tree species *Calophyllum inophyllum*, known locally as *nyamplung*, to measure its suitability for planting on degraded peatlands in Central Kalimantan. The trial plots were affected by fires twice in 2019. Trial Plot 1 was badly damaged during the first fire in July 2019, while the second fire in October that year affected trial Plot 2. The two plots in the two-hectare trial plot area are separated by a canal.

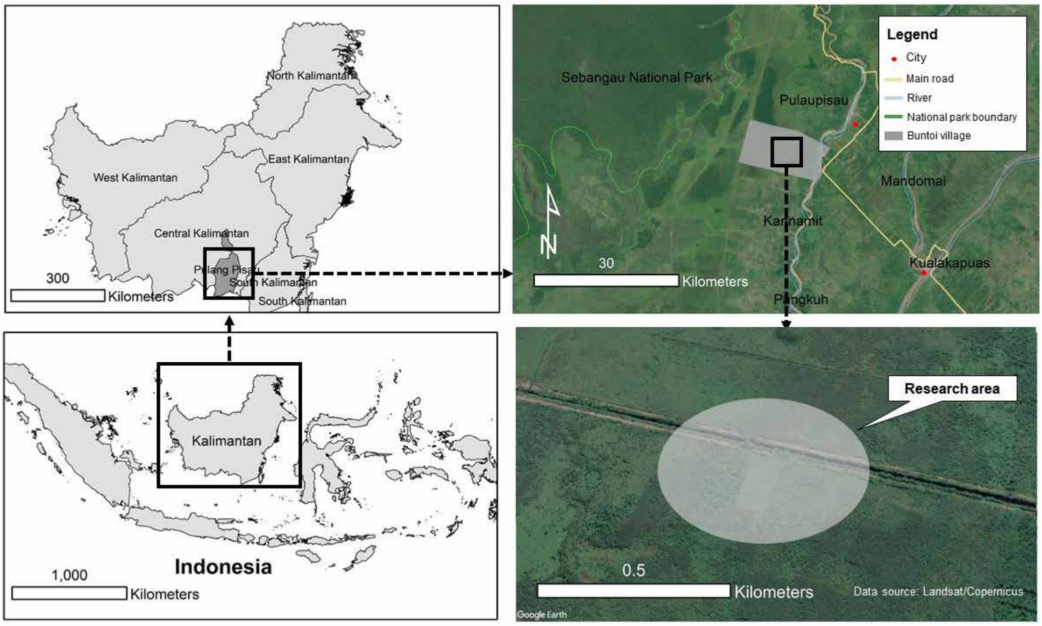


Figure 1. Study area in Buntoi Village, Pulang Pisau District, Central Kalimantan Province, Indonesia

8.1.2 Sampling design

Nyamplung trees were planted on the two-hectare plantation area with a plant spacing of 8 m x 8 m. A canal separates the plantation area into two one-hectare plots. A random sampling method was used to collect soil fauna specimens (Goehring et al. 2002; Witmer et al. 2003; Mathews et al. 2004). Sampling was conducted twice. The first samples were collected in August 2019 following a fire in Plot 1, while the second samples were collected in November 2019 after another fire in Plot 2. Equal numbers of sampling points (12) were established in each plot. In Figure 2 below, L1 to L12 represent planting rows, while each box with an 'X' represents a single tree. To ensure uniqueness in data collection, three different sampling point positions were employed: near trees; between trees in the same row; and between trees in different rows.

Four sampling categories (A, B, C and D) were established for this study, differentiated by plot conditions following the 2019 fires. A was the first sampling of Plot 1 (3 weeks after being fire affected), B was the second sampling of Plot 1 (15 weeks after being fire affected), C was the first sampling of Plot 2 (unburnt), and D was the second sampling of Plot 2 (3 weeks after being fire affected).

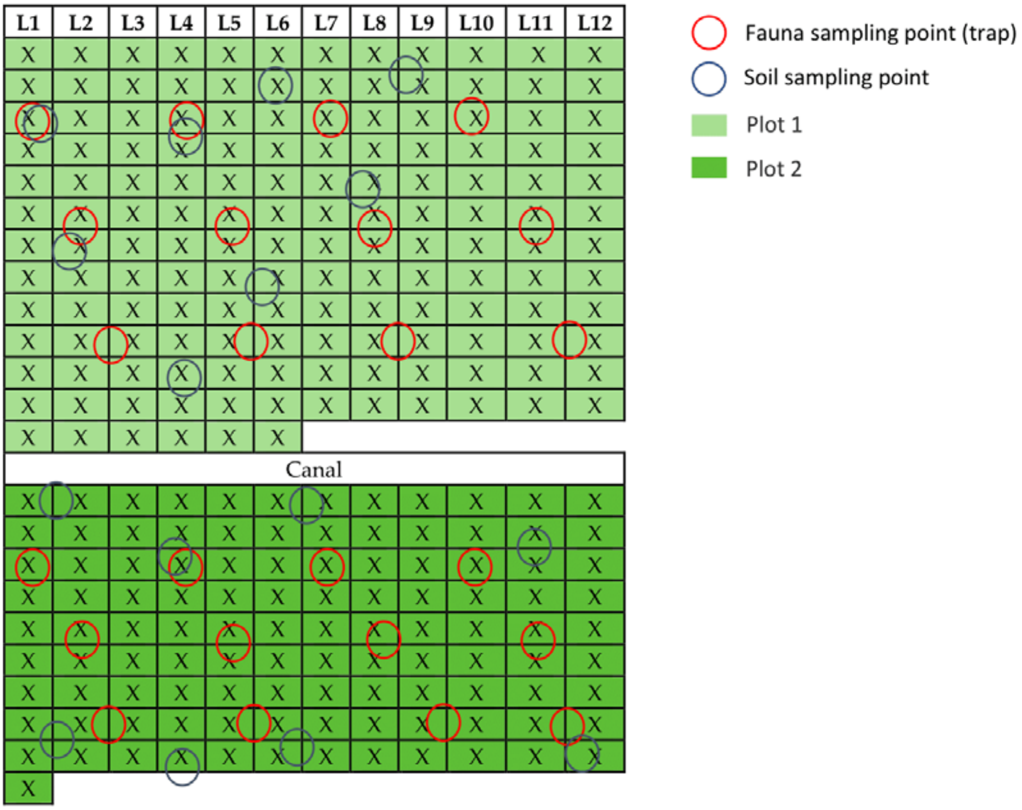


Figure 2. Sampling design

8.1.3 Soil fauna sampling

This study focused primarily on soil mesofauna and macrofauna. Soil macrofauna comprises insects, earthworms, isopods, molluscs and Myriapoda above 2 mm in size, while mesofauna consists of arthropods, mites, enchytraeids and Collembola below 2 mm in size (Maftu'ah et al. 2005). The pitfall trap method (Domingo-quero 2010) was used to trap surface macro/mesofauna. Pitfall containers were positioned by digging holes measuring 15 cm deep and 7 cm in diameter at the selected sampling points. Containers were placed at the defined sampling points and labelled. The pitfall traps collected hypogean and epigean fauna that crawled over the surface. These traps, called wet traps/kill traps and equipped with killing-preservative liquid, were used for the study. Considering the hazardous effects of chemical preservation (Weeks and McIntyre 1997), liquid detergent mixed with water was employed as it reduced surface tension allowing captured fauna to sink (Domingo-quero, 2010). The traps were set for 24 hours, following which the trapped fauna was hand sorted in the field (Suin 1997; Maftu'ah et al. 2005). Once sorted, trapped individuals were preserved in vials filled with 95% alcohol (FAO 2008) and delivered to the CIFOR laboratory in Bogor for identification.

For the first stage of identification, images of collected specimens were taken using a microscope fitted with a Leica MC170 HD camera operated with the help of Leica software (LEICA 2011). The Leica Application Suite (LAS) Version 4.4.0 used for this study provided easy-to-use research analysis with real-time, high-resolution images. Images focusing on key body parts (legs, wings/elytra) at different levels of magnification were necessary for identification at the order level. The second stage of identification employed a taxonomic system following morphological character according to Zhang (2011) by referencing the identification key for macro/mesofauna developed by Dr Antov Potapov from the University of Göttingen, Germany.

8.1.4 Soil sampling

Soil samples were collected from random sampling points at depths of 5 cm in August 2019 and November 2019 (Figure 2). Three replicate soil samples were taken from each sampling point and collected to examine their soil moisture content. In addition to soil moisture, the samples were collected to assess soil properties such as bulk density, soil temperature, pH, total micro-organisms, and water table depth in burnt and unburnt peat soils meeting standard criteria for environmental degradation under Republic of Indonesia Government Regulation No. 4/2001 (Wasis et al. 2019).

8.1.5 Data analysis

Soil fauna biodiversity data was processed using a species diversity index (H) and calculated using the Shannon-Wiener index (Shannon 1948) to show species biodiversity level (Ludwig and Reynold 1988). Species richness and species evenness data were also generated by employing the Margalef index (Margalef 1958) and Pielou index (Pielou 1966), respectively.

$H = -\sum_{I=0}^{S} p_i \ln \ln (p_i)$ = Shannon-Wiener species diversity index

$p_i = \frac{N_i}{N}$ = proportion of the total sample belonging to the i^{th} species.

$H_{max} = \ln \ln S$ = Maximum diversity possible

$E = \frac{H}{H_{max}}$ = Evenness

N_i = Number of individuals per species

N = Total number of individuals for all species

S = number of species = species richness

The gravimetric method (Reynolds 1970) was used to determine soil water content by drying soil samples at 105°C for 48 hours. Gravimetric water content (θ_g) is the water mass per dry soil mass. Measurements were taken firstly by weighing soil samples (m_{wet}); dehydrating them, and weighing the resulting dried soil (m_{dry}) (Bilskie and Scientific 2001). Similarly, soil pH was analysed by using a 1:2 ratio soil water suspension method (Jackson 1973).

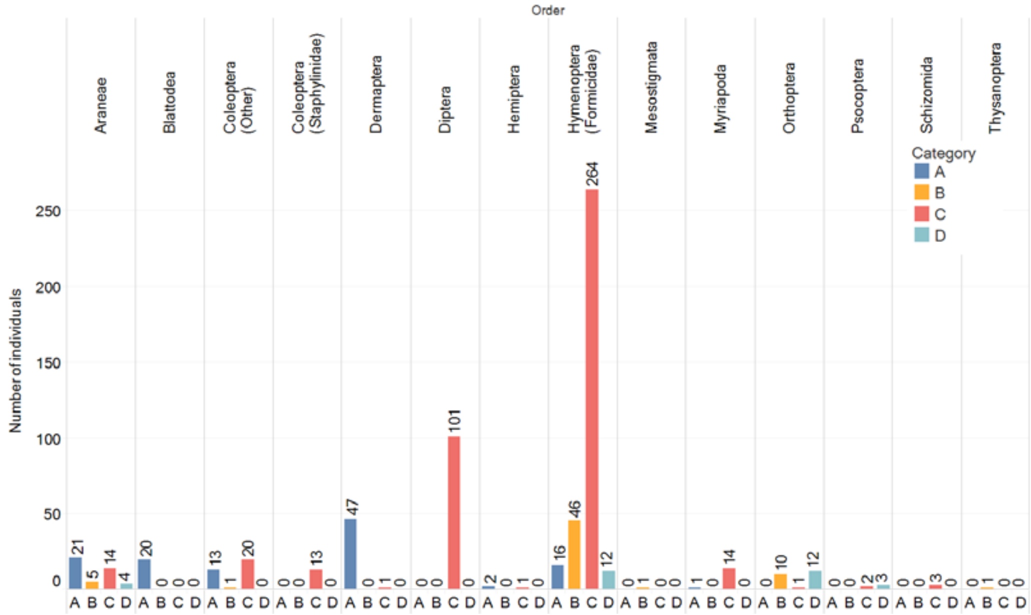
$$\theta_g = \frac{m_{water}}{m_{soil}} = \frac{m_{wet} - m_{dry}}{m_{dry}}$$

A total of 90 samples were collected from the four plot categories (A, B, C and D). Initially, research analysed correlations between variables with 95% confidence intervals to explore whether or not the different variables overlapped. Next, mean H and mean difference were calculated by category, by fire occurrence and by survival rate. STATA Version 14 was used to perform the data analyses.

8.3 Results

8.1.6 Soil fauna identification

A total of 649 soil fauna individuals were trapped during the study; 554 individuals from the first sampling period and 95 individuals from the second. A total of 24 species were collected from the first sampling period and 12 species from the second. These were categorized by order for comparative analysis. Later, during the laboratory identification process, they were classified as 14 orders of soil fauna (Figure 3). The most prevalent order was Hymenoptera (Formicidae), which was found in every plot. Of the 14 identified orders, only two – Coleoptera (Staphylinidae) and Schizomida – were exclusive to the unburnt area.



Note: A is the first sampling of Plot 1 (burnt), B is the second sampling of Plot 1 (burnt), C is the first sampling of Plot 2 (unburnt), D is the second sampling of Plot 2 (burnt)

Figure 3. Number of individuals by sampling category (A, B, C and D)

8.1.7 Soil fauna diversity

Numbers of individuals of every order in the burnt and unburnt areas as well as diversity indices for these areas are presented in Table 1. The Shannon diversity index showed greater species diversity (H) at sampling points where tree survival rates were higher than where they were lower (Table 1). Results show a significant correlation between peat fire occurrence and biodiversity (Table 2). We found the greater the fire damage to bioenergy trees, the higher the likelihood of diminished biodiversity. Further, peat fire had a detrimental impact on species richness.

Table 1. Soil fauna species diversity, species richness and species evenness

Order	**Category**											
	A			**B**			**C**			**D**		
	High (n=5)	**Medium (n=4)**	**Low (n=3)**	**High (n=9)**	**Medium (n=2)**	**Low (n=1)**	**High (n=8)**	**Medium (n=3)**	**Low (n=1)**	**High (n=6)**	**Medium (n=2)**	**Low (n=4)**
Araneae	19	0	2	4	1	0	12	1	1	2	2	0
Blattodea	20	0	0	0	0	0	0	0	0	0	0	0
Coleoptera (other)	10	1	2	0	1	0	15	5	0	0	0	0
Coleoptera (Staphylinidae)	0	0	0	0	0	0	3	10	0	0	0	0
Dermaptera	46	1	0	0	0	0	1	0	0	0	0	0
Diptera	0	0	0	0	0	0	39	62	0	0	0	0
Hemiptera	1	0	1	0	0	0	1	0	0	0	0	0
Hymenoptera (Formicidae)	12	1	3	25	14	7	36	228	0	10	0	2
Myriapoda	0	1	0	0	0	0	7	7	0	0	0	0
Orthoptera	0	0	0	8	1	1	1	0	0	5	4	3
Psocoptera	0	0	0	0	0	0	2	0	0	1	2	0
Schizomida	0	0	0	0	0	0	2	1	0	0	0	0
Total	108	4	8	37	17	8	119	314	1	18	8	5
S	6	4	4	3	3	2	11	7	1	4	3	2
H	**1.49**	**1.39**	**1.32**	**0.84**	**0.66**	**0.38**	**1.74**	**0.85**	**0.00**	**1.09**	**1.04**	**0.67**
$Hmax$	1.79	1.39	1.39	1.10	1.10	0.69	2.40	1.95	0.00	1.39	1.10	0.69
E	0.83	1.00	0.95	0.76	0.60	0.54	0.72	0.44	0.00	0.78	0.95	0.97

Note: High means high survival rate at the sampling point (all trees alive); Medium indicates one of two trees from the sampling point being dead; and Low means low survival rate (all trees dead). A is the first sampling of Plot 1 (burnt); B is the second sampling of Plot 1 (burnt); C is the first sampling of Plot 2 (unburnt); and D is the second sampling of Plot 2 (burnt).

Table 2. Correlation between variables

	H	S	E	Number of Individuals	Fire	Damage Level
H	1					
S	0.896**	1				
E	0.898**	0.702**	1			
Number of Individuals	0.083	0.353**	-0.016	1		
Fire occurrence	-0.447**	-0.565**	-0.241	-0.361**	1	
Survival rate	0.331**	-0.254	-0.279	-0.002	0.200	1

**high significance at a 95% confidence level

Average diversity index (H) value was highest for category C, where no fire had occurred (Table 3). By comparing the mean H values of categories A and B, we concluded that diversity recovers with time. Diversity index (H) values become higher as the level of damage decreases. Table 4 shows whether mean differences in diversity indices (H) were significant.

Table 3. Mean H by category, by fire occurrence and by tree survival rate

	Mean	Std Err	[95% Conf. Interval]	
By category				
A	0.373	0.120	0.131	0.616
B	0.451	0.120	0.208	0.694
C	0.842	0.120	0.599	1.085
D	0.309	0.120	0.066	0.552
By fire occurrence				
Unburnt	0.842	0.119	0.603	1.081
Burnt	0.378	0.069	0.240	0.516
By tree survival rate				
High	0.608	0.083	0.441	0.775
Medium	0.420	0.132	0.154	0.686
Low	0.228	0.146	-0.066	0.523

Table 4. Mean differences by category, by fire occurrence and by survival rate

	Contrast	Std Err	t	P>t	[95% Conf. Interval]	
By category						
C-A**	0.469	0.170	**2.75**	0.041	0.014	0.924
B-A	0.077	0.170	**0.45**	0.968	-0.377	0.532
D-A	-0.064	0.170	**-0.38**	0.981	-0.519	0.390
B-C	-0.391	0.170	**-2.3**	0.114	-0.846	0.064
D-C**	-0.533	0.170	**-3.13**	0.016	-0.988	-0.078
D-B	-0.142	0.170	**-0.83**	0.838	-0.597	0.313
By fire occurrence						
Burnt-Unburnt***	-0.464	0.137	**-3.39**	0.001	-0.740	-0.188
By tree survival rate						
Medium-High	-0.188	0.156	**-1.21**	0.455	-0.567	0.190
Low-High*	-0.380	0.168	**-2.26**	0.072	-0.788	0.027
Low-Medium	-0.192	0.197	**-0.97**	0.598	-0.670	0.286

* significant at a 90% confidence level; **highly significant at a 95% confidence level; *** very highly significant at a 99% confidence level

8.1.8 Soil properties

Soil moisture content for each category is presented in Table 5. Soil moisture content was higher during the second round of sampling than the first as rainfall was also higher. However, water table depth fell after fire. Table 5 shows the lower the survival rate, the lower the water level (water table depth).

Table 5. Comparison of environmental factors by category

		Properties						
Category		Water Table Depth	Soil Moisture	Bulk Density	WFPS*	Rainfall	Air Temperature	Air Humidity
A (n=8)	Mean	84.38	0.37	0.53	1.26	5.59	24.10	90.53
	Std Dev	18.17	0.18	0.07	0.26	0	0	0
B (n=8)	Mean	62.23	0.58	0.49	1.30	8.12	24.41	92.03
	Std Dev	10.38	0.13	0.06	0.21	0	0	0
C (n=8)	Mean	95.41	0.44	0.51	1.29	5.59	24.10	90.53
	Std Dev	20.19	0.24	0.13	0.46	0	0	0
D (n=8)	Mean	56.47	0.63	0.52	1.54	8.12	24.41	92.03
	Std Dev	13.00	0.15	0.11	0.63	0.00	0	0
Unburnt (n=8)	Mean	95.41	0.44	0.51	1.29	5.59	24.10	90.53
	Std Dev	20.19	0.24	0.13	0.46	0.00	0	0
Burnt (n=24)	Mean	67.69	0.53	0.51	1.37	7.28	24.31	91.53
	Std Dev	18.32	0.18	0.08	0.41	1.21	0.15	0.72
High (n=24)	Mean	77.34	0.50	0.52	1.37	6.86	24.26	91.28
	Std Dev	24.04	0.20	0.10	0.46	1.29	0.16	0.77
Medium (n=3)	Mean	67.63	0.67	0.50	1.39	7.28	24.31	91.53
	Std Dev	22.14	0.17	0.07	0.38	1.46	0.18	0.87
Low (n=5)	Mean	65.75	0.44	0.50	1.20	6.60	24.23	91.13
	Std Dev	6.86	0.20	0.06	0.25	1.38	0.17	0.82

* WFPS = Water-filled pore space

8.4 Discussion

Higher species richness and species diversity were recorded from samples taken in the unburnt plot than in those affected by fire, clearly signifying that peatland fires have significant impacts on soil mesofauna and macrofauna communities. A similar study in Mount Walat Education Forest in Sukabumi District, West Java Province, Indonesia, showed forest and land fires resulting in a decrease in soil macrofauna by an order of 17.65% (Syaufina 2008). Peat fire impacts can be even more severe, resulting in soil fauna mortality of 100% (Wasis et al. 2019). Another study in Indonesia also indicated similar results, with the average diversity index for soil fauna being lower in a burnt plot (0.76) than an unburnt plot (1.76) (Syaufina and Ainuddin 2011).

Burning peat increases soil porosity, decreases available water, increases soil permeability, and causes higher mortality in flora, fauna and microorganisms (Wasis et al. 2018). Burnt and dried peat soil is difficult to restore, and many lost soil fauna species are unlikely to return (Wibowo 2009). The presence of specific aboveground vegetation in unburnt areas helps in maintaining a greater diversity of soil organisms (Brennan et al. 2006). Unburnt habitats have displayed higher soil macrofaunal diversity in primary forest, palm oil plantation and industrial plantation forest ecosystems in comparison with burnt plots (Wasis et al. 2018), which supports the findings of this study.

Of the 12 orders recorded in burnt plots in our study area, individuals of Order Hymenoptera (Formicidae), representing most ant species, were recorded in high numbers (Figure 3, A-B) and were well adapted (Figure 3, C-D). This is because invertebrates, such as some ants, beetles, termites and spiders, can adapt to burning regimes (Swengel 2001) and are more likely to survive and evade heat because of belowground activity. In addition, burning and other disturbances, such as logging, provide open habitats as more favourable environments for ants (Andersen et al. 2009).

Soil moisture availability and related variables, including water table depth, are critical abiotic factors that affect soil animal communities and support soil invertebrates (York 1999; New et al. 2010; Keith 2012; Sylvain 2013). Soil moisture availability impacts soil fauna directly and indirectly by restructuring soil food webs and ecosystems (Sylvain 2013) – directly as fauna uses water for survival, and indirectly as soil moisture impacts the plants that fauna rely on (Xu et al. 2015). Given that burning and forest fires lead to topsoil moisture reduction and higher insolation levels (York 1999), we expected a negative response for fires on soil moisture. However, the study found no statistically significant correlation between soil moisture and peatland fires (Table 5). One possible explanation for this is that rainfall was higher in the burnt areas, resulting in more soil moisture (Table 5). Other reasons might be seasonal variables, soil nutrients, etc. In this regard, more comprehensive research into relationships between changes in soil conditions (nutrients, bacterial diversity, soil temperature, etc.) and soil fauna diversity is necessary.

8.5 Conclusions

Fires in Central Kalimantan Province have degraded peatlands and changed their biodiversity patterns. The peatland fires on community land in Buntoi Village adversely affected biodiversity indices and survival rates, thus having significant impacts on soil fauna biodiversity. Water table depth fell following the fires. We were able to establish which species are resilient and which species are vulnerable to fires in peatlands (Figure 3 and Table 1).

Overall, our results indicate that the changes in biodiversity and soil properties meet standard criteria for environmental degradation under Government Regulation No. 4/2001. Understanding the severe impacts of fire on peatlands will make people more aware and less likely to use fire for clearing and preparing peatlands, thereby prolonging their use.

This research had a number of limitations: (1) soil fauna was only identified to the order level due to time constraints; (2) sampling was only conducted twice due to budget and time constraints; and (3) no comparative research was conducted in other peatlands with different soil properties.

For more detailed insights into fire impacts on soil mesofauna and macrofauna communities, an intensive study with more replications and soil assessment considerations is recommended for future research. Comparisons of soil fauna biodiversity in different types of peatlands are also recommended for further study.

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CHAPTER 9

Growth performance of *Calophyllum inophyllum* in bioenergy trial plots in Bukit Soeharto Forest, East Kalimantan

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Abstract: The Government of Indonesia has committed to providing its entire population with energy through the National Energy Policy, which highlights the importance of diversification, environmental sustainability, and enhanced deployment of domestic energy resources. The contribution of new and renewable energy (NRE) to the nation's energy supply is mandated to reach 23% by 2025, with bioenergy an important NRE alternative. If developed and deployed appropriately, bioenergy plantations have potential to restore degraded land and enhance biodiversity and environmental services while supporting rural livelihoods. As a potential biofuel tree species suited to the tropics, *Calophyllum inophyllum* (*nyamplung*) is being tested across wide-ranging degraded forest conditions in Indonesia. *Nyamplung* is a potential biodiesel alternative as it grows well in harsh environmental conditions, produces non-edible seed oil, has high amounts of kernel oil and fruits profusely. Here we report growth performance in plantation trial plots established in February 2018, on previously burned land in Mulawarman University's Bukit Soeharto Research and Educational Forest. Growth of this two-year-old plantation is strong compared to other Indonesian sites, with average survival rate above 90% on Ultisol soil, which is classified as low fertility and acidic. The findings reveal that different doses of fertilizer applications and slope gradient have no significant effects on growth performance. In addition, trees have already started to flower and fruit, and are colonized by bird species and insects, including bees and butterflies. The study indicates that *nyamplung* adapts well to different land and soil types. Bioenergy plantations on degraded land are a promising approach for land restoration, and enhance native biodiversity and environmental services while providing a source of renewable energy.

Keywords: *Calophyllum inophyllum*, *nyamplung*, bioenergy, degraded land, growth performance, biodiversity, East Kalimantan
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9.1 Introduction

The Government of Indonesia has committed to providing its entire population with access to modern energy sources through its National Energy Policy (*Kebijakan Energi Nasional*), a document which highlights the importance of diversification and environmental sustainability, along with enhanced supply and deployment of domestic energy resources. These diversified energy sources include coal, oil, gas and new renewable energy (NRE). The contribution of NRE to the nation's energy supply is mandated to reach 23% by 2025 (GoI 2014). Bioenergy features as an important NRE alternative in the policy. To further the development of biofuel, the Ministry of Environment and Forestry (MoEF) has been assigned an important role in terms of providing unproductive forestland (GoI 2006a, 2006b). Based on recent MoEF data, 14 million hectares (ha) of Indonesian land is unutilized and classified as 'degraded', with the government earmarking it for conversion to plantations, energy production and infrastructure (MoEF 2018).

Calophyllum inophyllum, known locally as *nyamplung*, is one potential species able to produce bioenergy, especially for biodiesel, as it meets US and European Union biodiesel standards (Atabania et al. 2011). In addition, the resulting biodiesel has a higher calorific value compared to other energy species, such as jatropha, *Pongamia pinnata* and others (Arumugam and Ponnusami 2019). Further, *Calophyllum inophyllum* biodiesel can replace fossil diesel without any need for engine modification (Ong et al. 2011). The species produces non-edible seeds with significant amounts of kernel oil, and seeds can be harvested repeatedly from the age of four to five years until trees are 50 years old (Leksono et al. 2014a). *Nyamplung* flowers attract honeybees and are a great source of honey (Leksono et al. 2019; Rahman et al. 2019). The species can also be grown alongside a variety of agricultural crops, such as maize, soybean and rice, which provides an opportunity to apply climate smart agroforestry practices (Rahman et al. 2019).

Generally, *nyamplung* grows well in warm temperatures in wet or moderate conditions. It can grow in a wide range of soils, but grows best in sandy, well-drained soils in coastal areas. It is tolerant to wind, salt spray, drought and brief periods of waterlogging. It grows at altitudes of up to 500m, where annual rainfall ranges between 1,000 mm and 5,000 mm, and annual temperatures range from 7–18°C to 37–48°C (Friday and Okano 2006). In Indonesia, it has very wide natural distribution, from Sumatra in the west to Papua in the east, and from Java in the south to Kalimantan in the north. The plant is also tolerant to harsh environmental conditions, and requires little care and maintenance when it comes to cultivation (Leksono et al. 2017). In natural stands, *nyamplung* seed can have a crude *Calophyllum* oil (CCO) content of up to 58% (Leksono et al. 2014b). In line with the breeding strategy for biofuel yielding *nyamplung* (Leksono and Widyatmoko 2010), tree populations were selected from Gunung Kidul District, where trees produced the highest CCO content (50%–50.72%) among six *nyamplung* populations from Java, and were planted in Wonogiri District in Central Java to establish a provenance seed stand. A provenance seed stand is an area where a potential provenance or land race is established and managed intensively and entirely for seed production (Zobel and Talbet 1984). Through the above breeding programme, oil content was increased by 14%–19% (Leksono et al. 2019).

Despite the species having potential for biofuel production from non-edible oil, there are limited studies into the adaptability and suitability of *nyamplung* to different locations in Indonesia. This paper aims to communicate early findings relating to *nyamplung* growth performance on previously burned degraded land in East Kalimantan.

9.2 Material and methods

9.2.1 Study site

The study site is located at Mulawarman University's Bukit Soeharto Research and Education Forest (KHDTK HPPBS) in Kutai Kartanegara District, East Kalimantan (Figure 1). This 20,271-hectare area of forestland is a part of the Bukit Soeharto Great Forest Park (*Tahura*) and was assigned to Mulawarman University by the Ministry of Environment and Forestry (MoEF) as a special purpose forest estate (KHDTK) in 2014. Site characteristics of the trial plots in Bukit Soeharto and the provenance seed stand in Wonogiri (the source of *nyamplung* seeds for the trial plots) are shown in Table 1.

The soil in the study site is classified as Ultisol (formerly red-yellow podzolic), a soil with lower base status, which is more acidic in reactions than Oxisols. It has been formed from more acidic parent materials (like dacitic and liparitic tuffs) and is rich in quartz (Tan 2008).

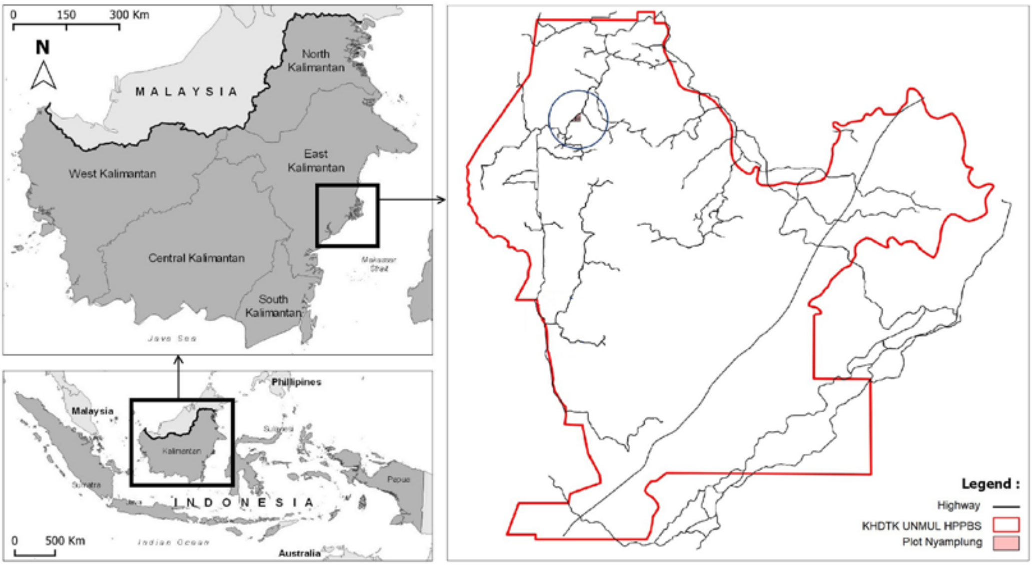

Figure 1. Location of the study site – Mulawarman University's Bukit Soeharto Research and Education Forest, East Kalimantan

Source: Map created by CIFOR, 2020

Table 1. Characteristics of the previously burned *Calophyllum inophyllum* (*nyamplung*) plantation trial plots in Bukit Soeharto Forest, East Kalimantan and the provenance seed site in Wonogiri, Central Java

Site characteristics	Bukit Soeharto	Wonogiri
Total area	20,271 ha	93.34 ha
Latitude (South)	00°47’47.5”	7°32’ – 8°15’
Longitude (East)	117°01’15.3”	110°41’ – 111°18’
Rainfall (mm/year)	2,000–2,500	1,878
Temperature (°C)	20 – 36	20 – 38
Altitude (m asl.)	117	141
Soil type	Ultisol	Vertisol
Last burned	2016	Never burned
Vegetation cover	Acacia, bamboo, scrub	Bamboo, *Dalbergia*, scrub

The area has experienced frequent fires since the late 1990s, with the last fire prior to the experiment being in 2016. Such fires lead to degradation of the forest and land, which is visually apparent from the species dominating the area, i.e., unplanted *Acacia mangium*, wild bamboo and scrub.

9.2.2 Research design and materials

The trial plot was established on a five-hectare area of the study site in early 2018 to examine the suitability of energy production tree species to degraded (previously burned) mineral soil. The trial plot was divided into five subplots with different slope gradients (see Figure 2). In February 2018, the plots were planted using genetic material from the *nyamplung* provenance seed stand in Gunung Kidul, Yogyakarta. This *nyamplung*, planted in a forest managed by the Center for Forest Biotechnology and Tree Improvement Research and Development (CFBTIRD), was found to have the highest crude *Calophyllum* oil (CCO) content of six *nyamplung* populations in Java (see Table 2).

Table 2. Crude *Calophyllum* oil (CCO) content of six provenance tree populations in Java

No.	Provenance/Land race	Dry seeds (kg)	Residual waste (kg)	CCO (kg)	CCO (%)
1.	Banyuwangi (East Java)	2.09	1.20	0.89	42.58
2.	Gunung Kidul (Yogyakarta)	2.10	1.08	1.02	48.57
3.	Purworejo (Central Java)	1.90	1.04	0.87	45.79
4.	Cilacap (Central Java)	2.10	1.25	0.85	40.48
5.	Ciamis (West Java)	2.00	1.20	0.80	40.00
6.	Pandeglang (Banten)	1.81	1.16	0.67	37.02

Source: (Leksono et al. 2014b)

Figure 2. Plot design for the *nyamplung* trial plots at Bukit Soeharto Research and Education Forest

The trial plots were arranged in a completely randomized design to examine responses of different NPK fertilizer doses and different slope gradients with the same doses. Two thousand *nyamplung* seedlings were planted with a spacing of 5 m x 5 m, aiming to allow space for the species to grow in width, given the main objective was to obtain seeds for oil production. The plots were divided into 15 permanent measurement plots (PMPs) with three replications for each plot. Two hundred and twenty-seven seedlings were randomly selected for regular measurement. Three different doses of NPK fertilizer were applied on different plots to examine growth performance: 50 g, 100 g and 200 g (Figure 3). Plot 1 and Plot 5 were given 100-gram and 200-gram doses of NPK respectively, while 50-gram doses were applied on plots 2, 3 and 4. The plots were monitored every three months between August 2018 and December 2019, with height, diameter and number of branches measured as growth parameters. Soil samples were collected from each plot with tree replication and analysed to examine soil fertility.

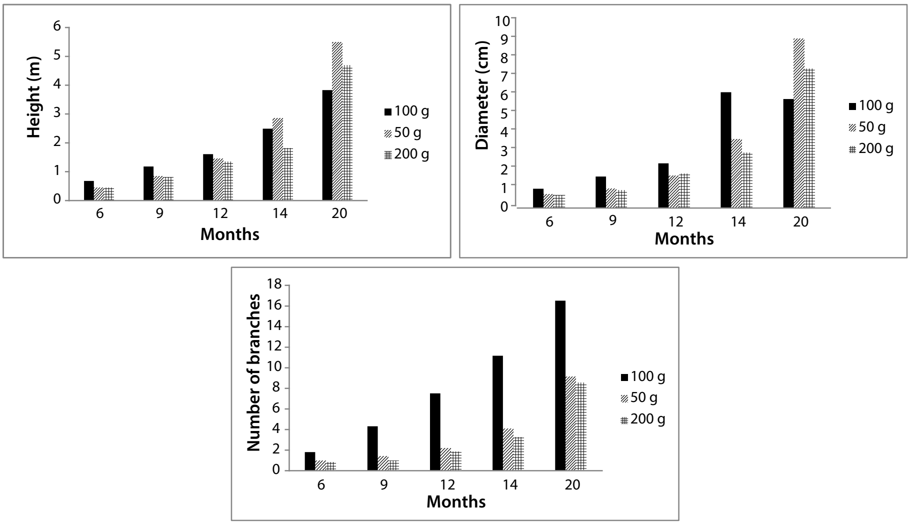

Figure 3. Mean growth performance after three different doses of NPK fertilizer

9.2.3 Data analysis

The trial plots were established with a two-way ANOVA statistical model to: i) examine the response of species growth after different treatments; and ii) examine the effect of slope gradient on species growth, regardless of treatment. Such two-way ANOVA analyses are commonly used to compare the effects of different treatments between two populations (Steel and Torrie 1980).

ANOVA was performed using the plots' mean data (Y_{ijk}) for growth, with the following linear model:

$$Y_{ijk} = m + T_i + P_j + e_{ijk}$$

where, m is the overall mean, T_i is the i-th treatment effect, P_j is the effect on the permanent measurement plot, and e_{ijk}. is the experimental error for Y_{ijk}.

An SAS (Statistical Analysis System) ver. 9.0 program was used to analyse the data.

9.3 Results and discussion

9.3.1 Results

Growth performance

Plant survival rate is one of the common parameters by which the health of plants is measured; it is dependent on environmental stress (Montenegro et al. 2013). First-year survival of transplanted seedlings plays a crucial role in the subsequent success of plantations (Sukhbaatar et al. 2020). Table 3 shows that at 20 months, the survival rate for seedlings in the trial plots was above 90%, varying between 91.1 (Plot 3) and 98.1 (Plot 2). These survival rates, however, tended to decline

Table 3. Survival rates of *nyamplung* under different treatments (i.e., NPK fertilizer doses and slope gradients)

Treatments	**Survival rate (%)**				
	6 months	**9 months**	**12 months**	**14 months**	**20 months**
Plot 1	93.8	91.7	91.7	91.7	91.7
Plot 2	100.0	100.0	100.0	100.0	98.1
Plot 3	100.0	100.0	97.8	93.3	91.1
Plot 4	100.0	97.8	95.6	95.6	95.6
Plot 5	97.8	97.8	97.8	97.8	95.6

after the seedlings reached 20 months old, particularly in Plot 3 where the rate declined almost 9% within 1.5 years.

Doses of NPK fertilizer

Different fertilizer doses resulted in differing growth characteristics (height, diameter, number of branches) in *nyamplung* seedlings in the trial plots (Table 4 and Figure 3). At the time of monitoring, there were no significant differences between plots and PMPs in terms of height. Height ranged from 0.8–1.2 m at nine months old and 3.8–5.5m at 20 months old. Likewise, treatments resulted in no significantly different effects on diameter growth between plots and PMPs, except at six months old. Diameter ranged between 0.7–1.0 cm and 5.9–9.1 cm at six and 20 months old, respectively. Analysis revealed that different treatments resulted in significantly different effects on the numbers of branches between

Table 4. Variance analysis of *nyamplung* growth performance after three different doses of NPK fertilizer

Source of variation	**df**	**Mean square**				
		6 months	**9 months**	**12 months**	**14 months**	**20 months**
1. Height						
Fertilizer	2	0.054**	0.134 ^{ns}	0.053 ^{ns}	0.818 ^{ns}	2.043 ^{ns}
PMP	2	0.069**	0.228*	0.489 ^{ns}	0.628 ^{ns}	0.403 ^{ns}
Error	4	0.002	0.027	0.412	2.086	9.252
2. Diameter						
Fertilizer	2	0.123 *	0.479 ^{ns}	0.387 ^{ns}	8.891 ^{ns}	6.399 ^{ns}
PMP	2	0.120 *	0.887 ^{ns}	3.118 ^{ns}	6.935 ^{ns}	12.785 ^{ns}
Error	4	0.040	0.310	1.091	19.983	10.441
3. Number of branches						
Fertilizer	2	0.836 **	9.994 **	30.434 **	57.221 **	50.692 ^{ns}
PMP	2	0.553 **	5.739 *	17.167 **	26.925 **	36.882 ^{ns}
Error	4	0.009	0.469	0.290	0.667	8.292

Remarks: df = degree of freedom; ns = non-significant; * = significant difference at 0.05 level; ** = significant difference at 0.01 level; PMP = permanent measurement plot plots and PMPs after six months old. The number of branches ranged from 0.8–1.8 at 6 months old and 8.5–16.5 at 20 months old. At the time of monitoring, a dose of 100 g of fertilizer gave the best results in terms of the number of branches.

Effects of slope gradient

Slope conditions showed no significant effects on growth performance between plots and PMPs until the age of 20 months, except in terms of diameter (Table 5, Figure 4).

Table 5. Variance analysis of *nyamplung* growth performance under three different slope conditions

Source of variation	**df**	**Mean square**				
		6 months	**9 months**	**12 months**	**14 months**	**20 months**
1. Height						
Slope	2	0.001 ^{ns}	0.068 ^{ns}	0.334 ^{ns}	1.328 ^{ns}	6.098 ^{ns}
PMP	2	0.058 *	0.273 *	1.689 *	4.349 ^{ns}	11.739 ^{ns}
Error	4	0.006	0.031	0.173	0.761	2.474
2. Diameter						
Slope	2	0.001 ^{ns}	0.019 ^{ns}	0.179 ^{ns}	0.505 ^{ns}	8.190 **
PMP	2	0.148 *	2.061 **	7.217 **	14.697 **	27.577 **
Error	4	0.014	0.007	0.058	0.251	0.001
3. Number of branches						
Slope	2	0.026 ^{ns}	0.277 ^{ns}	0.845 ^{ns}	2.086 ^{ns}	0.153 ^{ns}
PMP	2	0.490 **	3.229 ^{ns}	9.279 ^{ns}	20.718 ^{ns}	49.407 ^{ns}
Error	4	0.017	0.649	1.691	3.838	14.949

Remarks: df = degree of freedom; ns = non-significant; * = significant difference at 0.05 level; ** = significant difference at 0.01 level; PMP = permanent measurement plot

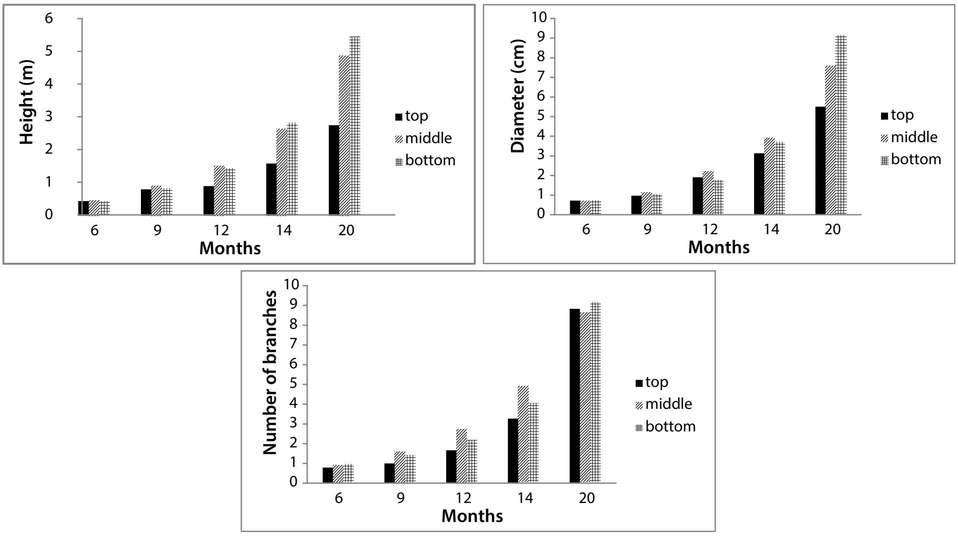

Figure 4. Mean growth performance under three different slope conditions

Table 6. Average soil chemical properties at the *nyamplung* trial plots in Bukit Soeharto Forest

Plot	pH H_2O	C-org (%)	N-Total (%)	C/N	P-Total (ppm)	Ca	Mg	K	Na	KTK	Base Saturation (%)
						(cmol$^{(+)}$/kg)					
1	4.48	1.46	0.19	7.51	44.37	0.59	0.43	0.20	0.05	14.28	10.01
2	4.49	1.14	0.21	5.47	21.09	0.15	0.31	0.06	0.05	8.08	6.69
3	4.27	1.13	0.20	5.59	39.16	0.15	0.15	0.14	0.05	7.36	7.47
4	4.93	1.13	0.23	4.98	29.35	0.30	0.30	0.11	0.04	42.23	1.59
5	5.14	1.32	0.22	6.06	10.18	0.28	0.28	0.16	0.04	41.40	1.99
Category	very acidic to acidic	low	low to moderate	very low to low	low to high	very low	very low to low	very low to low	very low	low to very high	very low

Height ranged from 0.8–0.9 m at nine months old and 2.8–5.5 m at 20 months old. Slope gradient had an apparent effect on diameter at the end of the observation period (i.e., at 20 months), when diameter ranged between 5.5 and 9.1 cm. Meanwhile, numbers of branches varied between 0.8–1.0 at six months old and 8.6–9.2 at 20 months old.

Soil chemical properties

Soil samples from the trial plots were collected and analysed in the soil laboratory to examine the soils' chemical properties. Table 6 shows that fertility in the study area is low, as indicated by low C-organic content and N-total content. The other indicator supporting low fertility in the area is low soil acidity (pH 4–5).

Landscape restoration and biodiversity

After two years of life as a plantation, the landscape had completely changed from degraded bare hills to a green landscape (see Figure 5). *Nyamplung* trees had already started to flower and fruit. Several bird species and insects, including bees and butterflies, had colonized the two-year-old trees. While flora and fauna surveying and analysis was not covered in this study, it was apparent that establishing bioenergy plantations on degraded land is a promising approach for land restoration and enhancing native biodiversity, while producing renewable energy.

9.3.2 Discussion

Survival rate and environment

Survival rate is an attribute that relates to the adaptation of a species to the planting environment (Birkinshaw et al. 2009). Geographic variation is often the most important

Figure 5. Conditions in the previously burned study site, before and after planting *nyamplung*

Figure 6. Bees, birds and butterflies colonizing *nyamplung* trees

characteristic relating to survival and adaptability (Leksono et al. 2017). The survival rate of *nyamplung* in the trial plots in Bukit Soeharto has been over 90%. This indicates that *nyamplung* from the provenance seed stand in Wonogiri adapted well to the trial site in Bukit Soeharto, despite the two locations having very different characteristics (see Table 1). This survival rate is the same as for *nyamplung* planted as the seed source in Wonogiri at six and 12 months after planting (Windyarini and Hasnah 2014). A study by Hani and Rahman (2016) revealed that four-year-old *nyamplung* tree had survival rates of 97.33% and 68.88%, respectively under agroforestry and monoculture systems on sandy soil in a coastal area of West Java. Meanwhile, among six provenance populations planted on sandy soil in ex-situ conservation plots in Cilacap, Central Java, survival rates at five years old ranged from 44% to 82% (Fiani 2015). Comparing two-year-old *nyamplung* trees on rocky land with thin topsoil in Gunung Kidul, where seeds came from eight different Indonesian islands, survival rates ranged between 77% and 86% (Leksono et al. 2015). Similarly, at 12 months after planting, *nyamplung* had the highest survival rate (52.4%–78.7%) of five species planted on former tin mining land (Cakyayanti and Setiadi 2014).

By the final monitoring visit of this study (24 months after planting), *nyamplung* trees in the trial plots had already started flowering and fruiting. This is another indicator of the good adaptability of *nyamplung* from the provenance seed stand in Wonogiri. The environmental and soil conditions (Tables 1, 3, 4 and 6) in the observation plots were not significantly different to those in Wonogiri, the source of the seeds. One noticeable difference was that of pH. Soil pH in the observation plots tended to be acidic, while in Wonogiri, pH was 7-8 (neutral) (Windyarini and Hasnah 2014). Nevertheless, this pH still meets the prerequisite for growing *nyamplung*, as it is tolerant to a pH range of 4–7.4 (Leksono et al. 2014a). Mean NPK nutrient content (Table 6) was higher in the trial plots than in Wonogiri (N = 0.08%; P = 1.86 ppm; K = 0.12) (Windyarini and Hasnah 2014). Fires on Ultisol soil can cause an increase in nutrients like N, P, K and organic matter, due to the addition of minerals found in ash and charcoal (Sumardi and Widyastuti 2002). However, fires can also destroy on-ground vegetation, with the result that soil structures are damaged, triggering erosion in the rainy season (Choiruddin et al. 2018).

The relatively high survival rates of *nyamplung* are because it can tolerate various soil types including clay, calcareous and rocky soils. *Nyamplung* is classified as a semi-tolerant plant but tends to be more suited to areas with full sunlight exposure (Mangopang and Prasetyawati 2015). In the coastal area of Bukit Soeharto Great Forest Park in East Kalimantan, *nyamplung* dominated at stand and pole stages, with 90.11% and 140.06%, respectively (Mukhlis and Sidayasa 2011). This domination was likely connected to the physical environment, as the coastal forest offers an ideal habitat for *nyamplung*, with a temperature of 25.4°C to 31.7°C, humidity of 75% to 97% and average rainfall of 2,000 mm to 2,500 mm per year. The high survival rate of *nyamplung* in the trial plots indicated high sunlight exposure supported growth. Climatic conditions in the coastal area fall under the same range as those of the *nyamplung* trial plots, although the areas have different soil types and acidity. The coastal area is sandier with high soil acidity, while soil in the trial plots is Ultisol with low soil acidity. As such, it appears possible to expand the planting of *nyamplung* from the Wonogiri provenance seed stand to different types of lands and soils based on its evident survival in these environmental conditions.

Implications of NPK fertilizer and slope gradient

At the beginning of the growth period, 50 g, 100 g and 150 g fertilizer dosage treatments had a significant effect on height, diameter and number of branches. However, the difference in growth performance became insignificant between plots and PMPs with the seedlings' increasing in age. The first year (six to 12 months) after planting is a critical phase for plants in terms of adapting from the nursery environment to the planting site in the field. Plants are more sensitive to external inputs, including fertilizer. Different doses of manure application also result in insignificant differences in height and diameter growth in teak plants (Sudrajat and Bramasto 2009). Fertilizer doses only gave fairly significant effects at the beginning of growth. This could be because the nutrient content in trial plot soils is sufficient to support growth, despite nutrient content being low (Table 6). At the operational scale, fertilizer application must be efficient, as excessive fertilizer may not produce significant results and will increase the operational costs of cropping (Sudrajat and Bramasto 2009). The results of different NPK fertilizer applications in *nyamplung* plants on the previously burned degraded land in Bukit Soeharto suggest that a lower dose (50 g) of fertilizer is sufficient.

Slope positions (top, middle, bottom) provide the same growth performance trends with each fertilizer treatment, up to the age of 20 months. Slope position as a treatment in its own right makes a real difference to growth parameters of height, diameter and number of branches at the beginning of growth (six to 12 months). At this stage, the greatest performance, diameter and number of branches were found at the bottoms of slopes (Figure 4), which may be due to additional nutrients leaching from higher up. At 14–20 months, slope position has no discernible effect, except on diameter. The insignificant differences could be down to nutrient content supporting plant growth until the age of 20 months (Table 5). Slope position also had no significant effect on the height and diameter of *sengon* trees at four months old, on revegetated land at the former Berau coal mine in East Kalimantan (Syauqie et al. 2019).

Flowering and fruiting

Calophyllum inophyllum generally starts flowering seven years after it is first planted (Bustomi et al. 2008). However, with intensive silviculture, *Calophyllum inophyllum* in Wonogiri's provenance seed stand in Central Java began to flower 18 months after planting (Leksono et al. 2016). In the previously burned trial plots in Bukit Soeharto Research and Education Forest, *nyamplung* was observed to start flowering and fruiting at the age of 24 months. This could be influenced by the low phosphorus (P) content in the soil (Table 6). The availability of water and P in the soil is a major limiting factor in the adaptability and growth of *nyamplung* in Wonogiri (Windyarini and Hasnah 2014). The reproductive cycle (flowering and fruiting) is one indicator of adaptation when a species is planted or developed in a particular location. As a comparison, in degraded peat swamps, *Calophyllum soulatri* begins fruiting at three years old (Darwo and Bogidarmanti 2016). The reproduction process is influenced by many factors; the formation of fruit is affected by the amount of synchronization, the maturity of males and female flowers, pollinator effectivity, amount of sunlight, altitude, temperature, rainfall, site conditions and management practices (Nurtjahjaningish and Widyatmoko 2012; Handoko et al. 2013; Putri et al. 2014).

Biodiversity and ecosystem services

There is ongoing concern and lack of agreement about the expansion of feedstock production for biofuels, and associated impacts on biodiversity and ecosystem services (Gasparatos et al. 2011). Depending on the location, previous land use, condition, planning and management, the establishment of biofuel crops may result in positive and/or negative impacts on the environment, including habitats, biodiversity, soil and water conservation (McBride et al. 2011). In this case, the plantation of bioenergy crops in a degraded and previously burned landscape demonstrated positive results on land restoration and habitat quality. However, as the research site is only just over two years old, it is too early to determine the full impacts on biodiversity and habitat quality.

9.4 Conclusions

Bioenergy crops have huge potential for restoring degraded landscapes and supporting climate and development goals in Indonesia. With a huge landmass and variety of climatic conditions, a wide range of biofuel species can be grown in different site conditions. This study demonstrated growth performance of two-year old *nyamplung* trees on an extremely degraded and frequently burned landscape, revealing it as a viable option for restoring degraded landscapes while growing an alternative source of energy. Findings prove that *nyamplung* has high adaptability to different soil types. The research shows that *nyamplung* has potential for being taken from experimental scale to pilots and wider implementation in various parts of Indonesia. Research and development organizations need to engage with small and medium enterprises and community groups to develop projects and business models at appropriate scales and in suitable contexts. We would urge that bioenergy development avoids arable land and forest conservation sites, to avoid food, energy and environmental conflicts.

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CHAPTER 10

Bamboo

Potential for bioenergy and landscape restoration in Indonesia

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Abstract: The growing demand for energy in Indonesia is driven by population growth, urbanization and economic development. Meeting this energy demand while reducing dependence on fossil fuels is vital. As Indonesia has a rich biomass base, bioenergy has become an important component of the nation's energy agenda. However, a crucial problem with bioenergy production is its potential impacts on food security, the environment and biodiversity. In this context, we discuss the characteristics, benefits and challenges of using bamboo, a perennial grass, as a potential provider of bioenergy feedstock in Indonesia. We describe the fuel characteristics of bamboo and the possibility of aligning its cultivation, production and utilization with environmental and development agendas. Its rapid growth, long root systems, easy maintenance and ability to grow in harsh conditions indicate its potential for use in restoring degraded lands. Therefore, we recommend in-depth research on the social, ecological and economic feasibility of using bamboo for bioenergy production.

Keywords: sustainable energy, land restoration, bamboo utilization, resource production
Link: https://www.cifor.org/knowledge/publication/7055/
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10.1 Bioenergy in Indonesia

Indonesia is the most populous country in Southeast Asia and is one of the fastest growing economies among the G20 nations. Indonesia's energy demand has increased significantly in parallel with its population growth, urbanization and economic development (National Energy Council 2016). The country's primary energy sources are fossil fuel based, with coal, oil and gas accounting for the largest share of its energy mix (Ministry of Energy and Mineral Resources 2017). The Government of Indonesia (GoI) has pledged to reduce greenhouse gas (GHG) emissions on the path to decarbonizing its economy. Through its Nationally Determined Contribution (NDC), submitted to the United Nations Framework Convention on Climate Change (UNFCCC) in 2016, Indonesia has committed to reducing GHG emissions unconditionally by 29% compared to a business-as-usual scenario by 2030, and by 41% with international help (GoI 2021). Meanwhile, Indonesia continues to face challenges in its energy sector. Although national energy security is improving, it remains below average and is less satisfactory than in developed and many other developing countries (Erahman et al. 2016). Many rural areas are still deprived of modern energy sources and largely depend on the direct burning of traditional bioenergy sources such as fuelwood, which leads to health problems (Huboyo et al. 2015) and has environmental impacts (Masera et al. 2015).

Ensuring universal access to affordable, reliable and clean energy services is the cornerstone of sustainable development as it is intrinsically linked to many other goals, such as no hunger, good health and well-being, poverty reduction and climate action (Griggs et al. 2017). Through its National Energy Policy, the Government of Indonesia is committed to providing energy to its growing population to help facilitate economic development and improve the well-being of the 11% of its population currently living below the poverty line. The policy emphasizes energy diversification, environmental sustainability and the utilization of domestic energy resources. As the international community is seeking affordable and clean renewable energy as a response to the current UN-driven sustainable development goals (SDGs), Indonesia is also looking to expand the share of renewables in its energy mix, which in 2020 stood at 11.20%. The country aims to increase this figure to 23% by 2025 (Ministry of Energy and Mineral Resources 2021), with bioenergy expected to contribute the highest share at 10%. Bioenergy is an important renewable energy produced from plant biomass and plant-derived residues and wastes to generate heat or electricity, or to produce liquid fuels for transport (Souza et al. 2015). It includes solid biomass (e.g., charcoal), liquids (e.g., bioethanol, biodiesel), and gases (e.g., biogas) produced from plants, wood and agricultural waste, among many other feedstocks. By 2025, bioenergy is projected to contribute to power plants with a total capacity of 5.5 MW, with 13.9 million kilolitres of biofuel; 8.4 million tons of biomass; and 498.8 million m^3 of biogas (GoI 2017).

Indonesia has vast land resources with large variations in elevation, climate, soil and physiographic conditions. This makes it possible to cultivate various types of plants for bioenergy production. However, if not planned and managed appropriately, bioenergy plantation expansion may lead to competition for land and water, and result in negative impacts on food production and biodiversity conservation (Popp et al. 2014). To avoid negative impacts on food security and biodiversity, and to diversify bioenergy production, it is important to identify suitable crops for use as bioenergy feedstock. In this context, this chapter discusses bamboo, a perennial grass, as an alternative raw material for sustainable bioenergy production in Indonesia through a review of scientific publications, reports and other grey literature to synthesize information on the benefits of using bamboo for bioenergy production.

Bamboos are distributed widely throughout the tropics and subtropics, and are the most widely utilized flowering perennials of family Poaceae, with its nearly 1,500 species under 87 genera (Ohrnberger 1999). Human use of bamboo dates back thousands of years. Traditionally, bamboo has been used as a source of food, fibre and fuel in Indonesia. The strong and flexible woody stem of bamboo is also used as a construction material and is frequently called the “timber of the poor”. In recent years, modern technology and demand for sustainable goods and services have expanded the utilization of bamboo beyond its traditional uses. For example, it is processed to design and develop durable tools, furniture and building materials. Currently, it can be utilized in many ways; in fact, it has more than 1,500 applications (Lobovikov et al. 2005). Due to its fuel characteristics, high productivity and short rotation, bamboo is now being explored as a potential feedstock to substitute fossil fuels for electricity power generation (Singh et al. 2017). Even though bamboo has been used traditionally in Indonesian culture for centuries (e.g., direct combustion for cooking), its use as a feedstock for modern bioenergy production is relatively new and is still in its infancy.

10.2 Energy properties of bamboo

As with other bioenergy crops, energy can be recovered from bamboo biomass in three main ways: thermal, thermochemical and biochemical conversion (Boyle 2004). Thermal conversion through direct combustion in the presence of oxygen is the most common way of converting solid biomass to energy (Demirbas 2001). The traditional method in Indonesia is using bamboo as fuelwood to generate heat for household purposes, such as cooking and boiling water. However, these conventional applications are relatively inefficient, often result in high indoor air pollution, and are a major health concern in the developing world (Fullerton et al. 2008). At the industrial scale, biomass like bamboo can be used in power plants to produce heat and power for electricity and district heating plants (Eisentraut and Brown 2012). The heat produced by direct biomass combustion in a boiler under controlled conditions can be used to generate electricity by running a steam turbine or engine. Direct combustion in power plants is the cheapest and most reliable route to producing power from biomass in standalone applications (IEA 2009).

Table 1. Fuel characteristics of bamboo compared to other biomass sources

Biomass Type	Ash (%)	Moisture (%)	Volatile Matter (%)	Heating Value (kJ/g)
Rice husk	12.73	12.05	56.98	14.63
Palm shell	3.66	12.12	68.31	18.44
Corn stalk	3.80	41.69	46.98	11.63
Bamboo	2.70	5.80	71.70	17.58
Acacia *	0.36	11.2	65.7	17.40

Sources: Sritong et al. 2012; Marsoem and Irawati 2016*

Another more efficient thermal conversion method is pyrolysis. Pyrolysis is the thermal degradation of biomass at a moderate-to-high temperature in the absence of oxygen. It can be used to convert bamboo biomass to solid fuels (charcoals), liquid fuels and gas (syngas) (Kerlero and Bussy 2000). Bamboo charcoal can be used as a fuel in the same way as coal, and it is a by-product of the biomass gasification process. Liquid fuels or pyrolysis fuels can be processed in a biorefinery to produce biofuels, while syngas can be used to produce power or electricity. In biochemical conversion, different strains of microorganisms are used to transform biomass to biogas or biofuels. The basic principle of biochemical conversion is the fermentation of sugar or other substances in the bamboo biomass into (bio)ethanol, methane and other fuels. Thus, bamboo biomass can be utilized in a variety of forms.

Bamboo has good fuel characteristics, such as high heat value and volatile content, and lower ash and moisture content, which makes it a suitable crop for bioenergy production (Scurlock et al. 2000; Sritong et al. 2012). In addition, in comparison to other biomass, bamboo has high cellulose and lignin content (Kuttiraja et al. 2013). Although these properties may differ according to species, location, maturity stage and management practices, among other things (Kumar and Chandrashekar 2014), in general, its overall heating value and composition lie somewhere between herbaceous biomass and hardwoods. The fuel characteristics (e.g., heating value and chemical composition) of bamboo are similar to those of other dedicated biomass feedstocks. Table 1 shows the fuel characteristics of giant asper *(Dendrocalamus asper)*, a common bamboo species found in Indonesia, and other biomass sources.

10.3 Local availability and familiarity

Bamboo is found in all provinces of Indonesia and covers approximately 2.1 million hectares (FAO 2005). There are around 135 species of bamboo in Indonesia (FAO 2005) either found naturally or cultivated deliberately. In the wild, bamboo is found in protected forests, national parks and nature reserves. As a planted crop, it is found in community forests, village gardens and in company plantations. In Indonesia, households can grow bamboo on areas for other land uses (APL), convertible production forest (HPK), permanent production forest (HP) and protection forest (HL) estates through non-timber forest product utilization permits (IPHHBK), and in certain nature reserve (KSA) and nature conservation (KPA) estates through environmental cooperation agreements. Bamboo is a familiar local plant, and is deeply rooted in Indonesian cultures and traditions as it has been used for centuries. Most farmers have some bamboo plants in their gardens. Indonesians commonly utilize bamboo as an essential material in their daily lives, using it for food, fuelwood for heating and cooking, and as a material for furniture and building. Its strong and flexible woody stems are also used as a construction material. This local familiarity could mean high community acceptance and willingness to participate in bamboo-based bioenergy production.

10.4 Synergy with food production and biodiversity

The production of feedstocks for bioenergy requires land and water. Consequently, bioenergy is often a source of debate because of its potential to impact negatively on food production and biodiversity due to land-use change and competition for resources (Immerzeel et al. 2014). Using bamboo as a feedstock for bioenergy can avoid these conflicts, especially when bamboo is grown on degraded and underutilized land. Bamboo is abundantly available, fast growing, and can grow on degraded and marginal lands or in combination with other crops in forestry or agroforestry systems, thus causing minimum competition for land (Mishra et al. 2014). As a fast-growing species that can develop on degraded lands, it can also establish a habitat for biodiversity, and with only sustainable harvesting of the crop, this habitat can be maintained in perpetuity. Also, increasing the availability of bamboo for bioenergy will help replace the use of fuelwood, thereby reducing pressure on forests. Where other bioenergy crops require replanting after harvesting, bamboo crops are usually ready in 5–12 years and can be harvested systematically each year without removing clumps, thereby ensuring the next 30- to 50-year life cycle (de Carvalho et al. 2013; Banik 2015; Benton 2015). In fact, managing a bamboo stand's age and density with annual thinning—using the derived material as feedstock—can increase bamboo productivity (Jianghua 2001).

10.5 Contribution to livelihood improvement

The agriculture and forestry sectors contribute significantly to Indonesia's economy, supplying nearly 12% of its GDP in 2017 (Bank Indonesia 2018). Thus, these sectors serve as a key driver for economic growth. Around 67% of Indonesia's total land area constitutes forest estate, while approximately 30% is used for agriculture (ADB 2015). In total, 49 million Indonesians, or around 41 percent of its total workforce, are employed in these sectors. Around 25,000 villages in Indonesia are located inside or near forest areas, with around 70% of their populations relying on forest resources for their livelihoods. These village farmers and communities could earn additional income by engaging in the cultivation, management and processing of bamboo for biomass feedstock and other bioenergy enterprises. Bamboo plantations are easy to establish and could be harvested for bioenergy production after three to five years, opening new avenues of income generation and a rapid boost to local economies. Bamboo also requires fewer agricultural inputs compared to other bioenergy crops (Ben-Zhi et al. 2005; Mishra et al. 2014), so its production would be a cost-saving resource for the people. Further, in contrast to estate crop plantations that only offer casual employment (Sinaga 2013), bamboo plantations under active management could also offer high numbers of long-term jobs for local people (Xuhe 2003). Indeed, the diversification of income streams would broaden livelihood options and reduce farmers' vulnerability to crop failure, helping them adapt to the changing climate (Bradshaw et al. 2004). In addition, the electricity generated through bamboo-fired power plants, mainly in regions that lack modern energy sources, could help local communities increase their household earnings by engaging in economic activities, such as running small industries. The bioenergy from bamboo-fired power plants could thus catalyse rural economic activities and provide a basis for the alleviation of poverty.

10.6 Climate action

The land use, land-use change and forestry (LULUCF) sector is a major contributor to Indonesia's GHG emissions, mostly from land-use change and forestry (68%) and agriculture (7%) (WRI 2018). Through its NDC, Indonesia has committed to reducing its GHG emissions by 29% compared to a business-as-usual scenario by 2030, which requires major interventions in the land use sector. Bamboo bioenergy offers a number of opportunities for emissions reductions in this sector. First, it can contribute to reducing emissions by replacing fossil fuel use for energy generation. Second, as a fast-growing species, it can rapidly sequester and store carbon in its biomass (Lou et al. 2010). Its rapid growth rate and high annual post-harvest regrowth make bamboo an excellent plant for carbon sequestration and storage (Lou et al. 2010). Although data on bamboo's carbon storage and sequestration potential in different cultivation systems is limited, several studies around the world have made estimations based on species composition, geographic location, environmental conditions and management practices.

Generally, the carbon density of bamboo forests (ranging from 168.7 to 259.1 t C ha^{-1}) is higher than the global average forest carbon density (86 t C ha^{-1}) (Lou et al. 2010). A study in China reported that a high amount of carbon (106.36 t ha^{-1}) is stored in a typical moso bamboo *(Phyllostachys edulis)* ecosystem (34.3 t ha^{-1} in the aboveground green vegetation and 72.2 t ha^{-1} on the forest floor and soil up to 60 cm in depth) (Zhou and Jiang 2004). In general, the carbon sequestration potential of many bamboo species is comparable to and often higher than that of many fast-growing tree species. For instance, the total carbon stock of five-year-old common bamboo *(Bambusa vulgaris)* is higher (15.53 Mg ha^{-1} year^{-1}) than that of fast-growing hardwood species like earleaf acacia *(Acacia auriculiformis)* (10.21 Mg ha^{-1} year^{-1}) (Sohel et al. 2015). Similarly, another study showed that in a mixed patch of bamboo species (*B. vulgaris*, *Bambusa balcooa* and *Bambusa cacharensis*) the rate of aboveground carbon sequestration ranged between 18.93 and 23.55 Mg ha^{-1} year $^{-1}$ (Nath and Das 2012).

10.7 Land restoration potential

Land degradation is the temporary or permanent decline in productive capacity of land that will result in negative consequences for agriculture, biodiversity and the environment (IUCN 2015). Further, as it affects people who depend on land-based economic activities, land degradation can lead to increased poverty in developing countries (Barbier and Hochard 2016). Consequently, land restoration has received increased attention as a measure for tackling the land degradation crisis, as reflected in the UN Sustainable Development Goals (SDGs) and in conventions such as the United Nations Framework Convention on Climate Change (UNFCCC), the United Nations Convention to Combat Desertification (UNCCD) and the Convention on Biological Diversity (CBD). Decades of exploitative land-use practices, such as mining and the drainage and conversion of peatlands and forests for agriculture, have resulted in large areas of degraded lands in Indonesia (Anshari et al. 2010; Margono et al. 2014; Wijaya et al. 2015; Gaveau et al. 2016). According to the “Indonesia Land Degradation Neutrality National Report 2015”, there are an estimated 24 million hectares of degraded land in Indonesia (UNCCD 2015). In an attempt to address this problem, Indonesia has taken several measures to restore its degraded lands (UNCCD 2015).

However, the biophysical and legal constraints associated with this land and the high costs of reclamation often challenge restoration efforts (Sayer et al. 2004; Sabogal et al. 2015; Stayi and Lal 2015). The restoration of large areas of degraded lands in Indonesia using biophysical measures will require significant investments in time and money. Though restoration costs are difficult to estimate, as they depend among other things on location, method and level of degradation, literature suggests that restoration costs using forest species can generally exceed USD 2,300 per hectare (Sukhdev et al. 2010). This implies long timeframes for productivity and financial returns, which can make farmers and investors hesitant to engage in restoration. In such cases, one common approach to minimizing costs is to plant fast-growing species that can grow in low fertility soils with minimum management intervention (Yu and Peng 1996). Thus, the ecological properties and economic savings and benefits of bamboo make it a unique plant for land restoration.

Bamboo can grow well in degraded and marginal soils with low fertility, and requires little fertilizer or water in comparison to other traditional sources of biomass (Ben-Zhi et al. 2005; Mishra et al. 2014). This implies that, even with less resource input, bamboo can thrive in severely degraded areas where other native species cannot grow. Further, the extensive fibrous root and rhizome systems, dense foliage, and leafy mulch of bamboo stabilize soil, control soil erosion and retain water (Ben-Zhi et al. 2005). Leaf litter from bamboo adds organic matter to the soil and contributes to the fertility of degraded soil. Further, bamboo does not require significant investments and, once a plantation is established, it can be managed without any special maintenance. As bamboo is fast growing and can be harvested continuously for three to four years without replanting, it would yield more rapid returns on investments, thereby attracting investors and farmers. Smallholder farmers could play a cost-effective role in land restoration, and, since they are already used to cultivating bamboo, it would be easy to apply bamboo to land restoration purposes in Indonesia. As the availability of managed bamboo increases, households would also switch to bamboo slats as a renewable alternative to fuelwood, thus bamboo could also help reduce deforestation. Furthermore, bamboo would help diversify landscapes, providing food and habitat for numerous species of insects, birds and other animals (Lou and Henley 2010). Some bamboo species contain high levels of starch and nutrients that are preferred by some wildlife species (Li et al. 2003; Reid et al. 2004; Song et al. 2011).

Although the use of bamboo for land restoration remains relatively small-scale, several initiatives have shown successful results and high potential for implementation at larger scales (FAO and INBAR 2018). In India, for example, a bamboo-based landscape project which commenced in 1997 has been successful in rehabilitating over 85,000 hectares of degraded lands while supporting thousands of livelihoods (Benton 2014). Several members of the International Network for Bamboo and Rattan (INBAR) are promoting the use of bamboo for land restoration as part of the Bonn Challenge (FAO and INBAR 2018). Recent bamboo-based restoration programmes include the Chinese State Forest Administration's plan to restore 3 million hectares, a plan to restore at least 500,000 hectares in the Philippines, and India's programme to restore around 100,000 hectares (Buckingham 2014). Indonesia could draw lessons from other tropical countries on using bamboo as a restoration species. Its capacity for rapid growth on degraded land with few production inputs, for stabilizing and adding organic matter to soil, and yielding biomass continuously without replanting makes bamboo a unique plant for land restoration in Indonesia.

With proper harvesting and management plans, bamboo plantations established for bioenergy could also help Indonesia to achieve goals signed under initiatives such as the Forest Landscape Restoration (FLR) (Bonn Challenge 2015), the New York Declaration on Forests (2014), and other UN conventions. Using bamboo for the restoration of degraded lands could create ecological and economic benefits for local communities and support the government's climate and development goals. However, bamboo should not be a substitute for native vegetation in restoration efforts, and should only be planted on degraded lands where planting native vegetation is not ecologically feasible.

10.8 Potential challenges

Although bamboo provides many ecological and socioeconomic benefits, there can be several challenges in its cultivation and management for bioenergy production. First, if bamboo plantations are not managed properly, the plant can pose a threat as an invasive species, as it can displace the surrounding native vegetation (O'Connor et al. 2000; Richardson and Canavan 2015). In addition, bamboo monocultures may increase forest cover, but may also simplify forest structure and modify or decrease biological diversity (Xu et al. 2008, 2015). Further, planting bamboo could pose a potential risk to biodiversity and food security if farmers clear-cut native vegetation or convert farmland to bamboo plantations in the pursuit of higher profits (Song et al. 2011). Even though bamboo requires fewer pesticides and fertilizers than other crops, intensive management involving harmful chemicals in the pursuit of higher production could still cause land and water pollution (Mariyono et al. 2018). Like other dedicated bioenergy crops, bamboo may also compete with food crops for land and water if it is grown on agricultural land. Addressing these issues is crucial when considering the suitability of bamboo for bioenergy production.

10.9 Conclusion

This paper discusses the potential of bamboo as a feedstock for bioenergy production and delivering other socioeconomic and environmental benefits in Indonesia. We believe that with proper planning, management and harvesting, bamboo has great potential for use as a feedstock for bioenergy production in Indonesia. Bamboo is abundantly available, familiar to local people, fast-growing, has multiple uses, can rapidly store and sequester carbon, can grow on degraded lands, and has good fuel characteristics for modern bioenergy production. The integration of multi-purpose perennial bamboo crops in energy systems in Indonesia could contribute substantially to achieving renewable energy targets while supporting land restoration objectives by offsetting the high costs involved in meeting the restoration goals of the Bonn Challenge. Yet, there is a dearth of literature on bamboo in the Indonesian context, and, to our knowledge, no studies have been conducted on the social, economic and ecological feasibility of using bamboo for bioenergy. We recommend further studies on the management of bamboo in the country, such as how much bamboo is locally available for bioenergy production, what species are best suited for bioenergy production, the extent to which GHG emissions would be reduced by using bamboo, where potential areas for future plantations are located, and other feasibility studies to explore the potential of bamboo in the country.

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CHAPTER 11

Pongamia as a potential biofuel crop

Oil content of *Pongamia pinnata* from the best provenance in Java, Indonesia

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Abstract: *Pongamia pinnata* (L.) Pierre is a fast-growing, leguminous and multipurpose tree species. It grows on degraded and marginal land in South and Southeast Asia. It produces non-edible seeds, the oil of which is a potential biofuel. In Indonesia, pongamia is widely found on all islands, but mostly to the west of the Wallace Line, in Banten, East Java, South Sumatra and West Java provinces. The economic viability of pongamia depends on the number of seeds per tree and the oil content of seeds. Studies on pongamia in Indonesia, with oil extracted using a simple mechanical expeller press, revealed that trees growing in Ujung Kulon National Park in Banten Province produce seeds with a higher oil content (15.59%) than those growing in the provinces of East and West Java. In this study, the oil content of 48 individual trees from Ujung Kulon National Park were analysed using a solvent extraction method. As a control, bulk seed was extracted using two different methods: 1) a Fabricant mechanical screw expeller press; and 2) solvent extraction. The results showed highly significant variance in oil content. Oil production of individual trees processed using the solvent extraction method reached 44% (varying from 26.61% to 44.68%), substantially higher than those using mechanical pressing at only 15% to 19%. Findings show that genetic factors, extraction machines and method of extraction can all influence pongamia oil production. The quality and genetic diversity of the seed source is also extremely important for industrial plantation forest programmes for bioenergy and land restoration in Indonesia.

Keywords: Biofuel crop, crude oil content, Pongamia pinnata, solvent method
Link: https://www.cifor.org/knowledge/publication/7903/
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11.1 Introduction

Pongamia pinnata (pongamia) is a legume tree with seed containing oils and fatty acids, which has been identified as a possible source of biofuel as well as having medicinal value. It is one of the few nitrogen fixing trees (NFTs) to produce seeds containing 30% to 40% oil suitable for biodiesel production (Chaukiyal et al. 2000; Dwivedi et al. 2011; Bobade and Khyade 2012; Samuel et al. 2013). The species has several benefits including: (i) a higher recovery and quality of oil than other crops; (ii) no direct competition with food crops as it is a non-edible source of fuel; and (iii) no direct competition with existing farmland as it can be grown on degraded and marginal land. In addition, as a legume it also fixes nitrogen from the soil, thus minimizing the need for fertilizers (Balooni and Singh 2001; Lal 2006; Kesari and Rangan 2010). Furthermore, pongamia flowers attract honeybees which in turn can help support rural economies. Due to its deep roots, it is also drought tolerant and can survive temperatures ranging from 5°C to 50°C. Pongamia is found in coastal areas, along limestone and rocky outcrops, and along the edges of mangrove forests, tidal streams and rivers (Sidiyasa et al 2012; Ramachandran and Radhapriya 2016).

The most useful product from pongamia is biodiesel (Abadi et al. 2016). In India, billions of pongamia trees are cultivated commercially for a sustainable biodiesel industry (Dwivedi et al. 2011). The aviation industry is looking for renewable jet fuels (Hendricks et al. 2011), and bio-derived jet fuel could be a viable alternative for the industry (Islam and Bari 2016).

It is well known that success in the establishment and productivity of forest tree plantations is determined largely by the species used and its seed source or provenance. A provenance is the original geographic area from which seed or other propagules are obtained (Zobel and Talbert 1984). Pongamia has a varied habitat distribution and can grow in a wide range of conditions. In Indonesia, the species occurs mostly to the west of the Wallace Line, though some trees can also be found to the east. On Java, pongamia can be found in Ujung Kulon National Park (Banten Province), Pangandaran (West Java Province), Alas Purwo National Park (East Java Province), and in other provinces (Djam'an 2009; Sidiyasa et al 2012; Aminah et al. 2017; Jayusman 2017). The wide natural distribution of pongamia offers a large geographical area from which to select the best provenances for genetically improved seed. This genetic variation could then be used in selection and breeding programmes.

Studies on *pongamia* in Indonesia, with oil extracted using a simple mechanical expeller press, revealed that trees grown in Ujung Kulon National Park in Banten Province produced seeds with a higher oil content (15.59%) than those grown in the provinces of East and West Java. However, this content was lower compared to results from various provenances in other countries using Soxhlet extractor equipment. To ascertain the maximum oil potential of pongamia, this study analysed the oil content of pongamia seeds derived from 48 individual trees growing in Ujung Kulon National Park. The study compared two improved extraction methods and compared these with available literature.

11.2 Materials and methods

11.2.1 Survey and seed collection

Seeds used for this analysis were obtained from Ujung Kulon National Park (UKNP) in Banten Province, which based on studies from 2015 and 2016, was considered the best provenance for pongamia on Java (Leksono et al. 2015; Jayusman and Pudjiono 2017). The park is located on the western tip of Java (Figure 1), and has a total area of 122,955 ha comprising a terrestrial area of 78,619 ha and marine area of 44,337 ha (UKNP Office 2015). The area includes the volcanic island group of Krakatoa in Lampung Province, and other islands including Panaitan, as well as smaller offshore islets such as Handeuleum and Peucang in the Sunda Strait.

A survey was conducted in 2018 to identify and select pongamia parent trees for seed extraction and genetic material. The seed from 48 trees was collected in 2019 for oil content analysis in 2019 and 2020.

The study was a continuation of previous studies in 2015 and 2016, which used pongamia genetic material and provenances from three areas of natural forest – Ujung Kulon National Park (Banten Province), Batu Karas-Pangandaran (West Java Province) and Alas Purwo National Park (East Java Province) – representing the natural distribution of pongamia on Java (Leksono et al. 2015; Jayusman 2017). Table 1 presents the site characteristics of the three provenances.

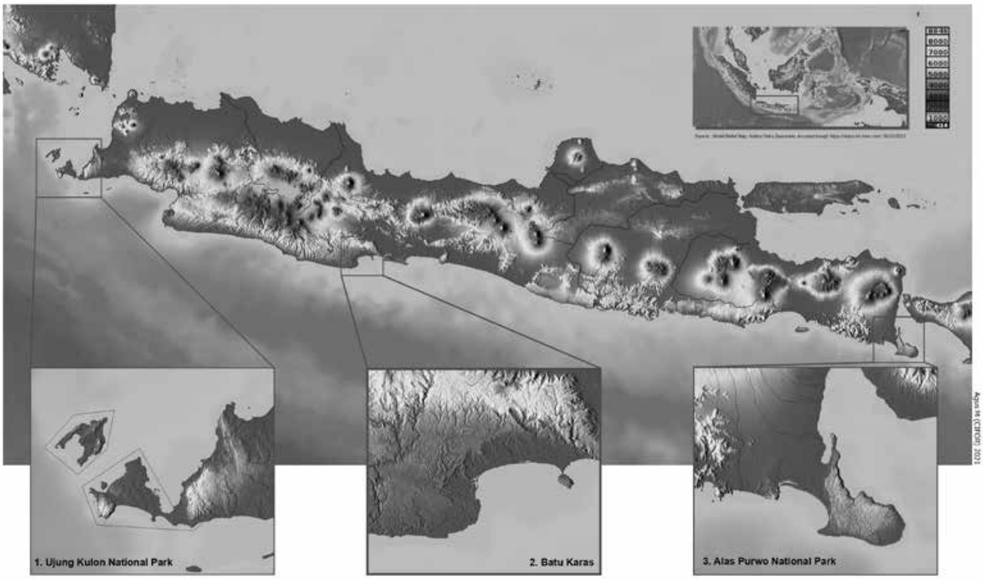

Figure 1. Location of Ujung Kulon National Park (Banten Province), Batu Karas-Pangandaran (West Java Province) and Alas Purwo National Park (East Java Province) Indonesia.

Table 1. Site characteristics of three provenances on Java

Characteristic*	**Ujung Kulon (Banten)**	**Batu Karas (West Java)**	**Alas Purwo (East Java)**
Latitude (South)	06°52’17”	07°41’15”	8°26’45”
Longitude (East)	102°02'32"	108°39'32"	114°20’16“
Altitude (m asl.)	0–8	0–4	0–15
Rainfall (mm per year)	3,250	2,987	2,079
Temperature (°C)	25–30	25–30	25–30
Dry season	May – September	May – September	June – October

*Sources: Leksono et al. 2015; Jayusman 2017

11.2.2 Materials and equipment

Fruit pods (300 g – 400 g) were opened manually to release seeds, which were then broken and divided into three seed samples. Materials for crude oil analyses included n-Hexane, water, paper filters and seeds. Tools used to conduct the research included an analytical balance, dry seed blender, electric stove, distillation set, stone boiler, thermometer, glass funnels and glass beakers.

Two pieces of equipment were used for extracting oil from the pongamia seeds: 1) a Fabricant mechanical screw expeller press and 2) a Soxhlet extractor. Pongamia seed pressing and oil analyses were conducted in the Bioenergy Laboratory at the Research and Development Centre for Forest Biotechnology and Tree Improvement (P3BPTH) in Yogyakarta.

11.2.3 Methods

The study applied two improved methods to extract pongamia oil: 1) mechanical pressing for bulk seed and 2) solvent extraction for bulk seed and individual seeds. Mechanical pressing is one of the oldest methods used for oil extraction. In principle, the seeds are placed between barriers where the volume available to the seed is reduced by pressing, thereby forcing oil out of the seeds. The solvent extraction method is, amongst other factors, based on the ability of the solvent to dissolve oils and to extract them from the seeds. It is the most commonly used method, and usually carried out either as a batch or continuous process (Nde and Foncha 2015).

11.2.4 Oil extraction: The mechanical press method

This method required more samples than the solvent method. The process started with sun drying the seed samples for one to two days, or in a cabinet dryer at 80°C to obtain dry seed with a moisture content of 8% to 12%. Prior to pressing, readied samples were heated to 75°C to 80°C for five to ten minutes to ‘loosen’ the oil from the cake.

Figure 2. Pongamia oil extraction process using a mechanical press: (a) pongamia pods/fruits, (b) dry pongamia seeds, (c) pressing process, (d) filtering process, (e) pongamia oil

To ease the flow of oil, the seeds were gradually inserted into the screw press until raw oil and residue were released. This process was done repeatedly depending on the condition of the seed material. Usually, raw oil could only be extracted after the resulting residue was completely dry. The oil content could then be quantified once it had gone through a filtering process (Figure 2).

11.2.5 Oil extraction: The solvent method

The seeds were ground into fine particles of around 20 g using an appropriate size blender. The Soxhlet apparatus was set up, and 150 ml of hexane liquid solvent was added from above to a thimble made of filter paper, then heated to evaporate the solvent. N-hexane is commonly used in chemical extraction because of its ability to extract more oil than other methods (Bhuiya et al. 2015). The temperature was stable at 75°C to 80°C during the process. Reflux was achieved through a condenser attached to the main chamber. The oil extraction process was carried out until all of the oil had been released from the seeds, as indicated by the n-hexane colour indicator drip returning to its pre-process colour. The resulting material was a mix of raw oil and n-hexane solution. To obtain pure pongamia oil, the raw material was separated using a distillation process (Figure 3).

Figure 3. Pongamia oil extraction process using the solvent method: (a) seed grinding, (b) thimble in chamber, (c) oil extraction process by Soxhlet extractor, (d) raw oil and n-hexane solution, (e) distillation process, (f) pongamia oil

11.2.6 Data analysis

The pongamia oil content was determined in order to examine variance in oil content potential. The formula used to calculate oil content parameters was as follows (BSN 2017):

$$\text{Oil content} = \frac{\text{Weight of extracted oil}}{\text{Seed weight}} \text{ X } 100\%$$

Analysis of variance between trees in the sampling location (Ujung Kulon National Park) was performed using individual tree data (Y_{ij}) for oil content with the following linear model:

$$Y_{ij} = \mu + F_i + \varepsilon_{ij}$$

where, μ is the overall mean, F_i is the i-th tree or family effect, and ε_{ij} is the experimental error for Y_{ij}.

SAS (Statistic Analysis System) ver. 9.0 was applied to run the analysis of variance.

11.3 Results and discussion

11.3.1 Oil content of pongamia oil

Pongamia oil content extracted from seeds from the three provenances in an earlier study using a simple mechanical screw expeller press made by a home industry workshop is presented in Table 2.

The results of the pressing procedure (Table 2) using a simple screw expeller press demonstrate that the average oil content potential from dry seed is 14.4%. Oil content varied significantly between the three provenances, ranging from 13.13% to 15.59%, with the highest oil content obtained from the Ujung Kulon National Park provenance. High variance in oil content between samples from the three provenances suggested that an improvement programme through pongamia provenance selection could be implemented and be very effective.

In forests, tree variations occur due to many factors, and most certainly include provenance or geographic race variations. Genetically controlled geographic differences are often large. Differences can be of key importance and the success of any tree improvement programme depends upon knowledge and use of geographic variation within the species of interest (Wright 1976; Zobel and Talbert 1984). Therefore, the determination of what constitutes a potential geographic source is very important when a tree improvement programme is implemented.

However, the oil content of trees from the three study provenances (Table 3) was lower compared to the results of provenance variance in Madhya Pradesh, India using a Soxhlet extractor, which ranged from 33.31% to 39.01% (Rahangdale et al. 2014). Using the same method (solvent extraction), seeds from Carmen and Agusan del Norte in the Philippines produced pongamia oil content of 28.18% to 41.32% (Razal et al. 2012), while seeds from Queensland and the Northern Territory in Australia had oil content of 36.7% to 37.74% (Arpiwi 2013). Other researchers have also reported pongamia oil content in the range of 27% to 39%. with extraction from kernels using traditional expellers yielding up to 26% oil (Meher et al. 2008), and varying between 30% and 40% in India (Dwivedi et al. 2011). This

Table 2. Oil content of pongamia from three provenances in Indonesia

Sample	**Oil content (%) ***		
	Ujung Kulon (Banten)	**Batu Karas (West Java)**	**Alas Purwo (East Java)**
1	15.82	14.25	13.05
2	15.44	14.54	13.23
3	15.52	14.67	13.12
Average	15.59	14.49	13.13

*Source: Jayusman and Pudjiono 2017

Table 3. Pongamia oil content from the best provenance by extraction method

No.	Mechanical Press Method			Solvent Method		
	Seed weight (g)	Oil content (g)	Oil content (%)	Seed weight (g)	Oil content (g)	Oil content (%)
1	121.68	22.06	18.13	21.25	5.81	27.34
2	146.00	23.24	15.92	20.53	5.83	28.40
3	122.72	22.46	18.30	21.46	7.55	35.18
4	130.90	21.6	16.50	21.92	7.02	32.03
5	146.00	28.62	19.60	20.86	8.19	39.26
	Average		17.69			32.44

would suggest that generally, pongamia seed has an oil content in excess of 25%, and that oil content may vary depending on provenance, time of collection, age of tree and processing method or equipment used (Leksono et al. 2014).

To find the maximum oil potential of pongamia seed from the Ujung Kulon provenance, oil content verification was carried out in 2019–2020 using better equipment and methods: 1) a mechanical pressing method using a Fabricant screw expeller press (Figure 2); and 2) a solvent method using a Soxhlet extractor (Figure 3). Both processes produced more oil (Table 3) than the screw press technology used previously (Table 2).

The results in Table 3 show that a mechanical Fabricant screw expeller press produced 2% – 25% more oil (in the range of 15.92% – 19.60%) than the simple screw press (15.44% – 15.82%). This was because the pongamia residue (waste from pressed seeds) from extraction using the simple screw press was still thick and wet, and the maximum amount of oil had not been extracted. In contrast, using the Fabricant screw expeller press was a more optimum seed pressing system and the waste was very thin and dry (Figure 2). Oil content using the solvent method varied from 27.34% to 39.26% (Table 3), which was much higher than from both screw expeller presses, despite being from the same provenance. Oil content was not significantly different to the results of mechanical extraction using the same method reported in previous research. This suggests that differences in oil content are not only influenced by genetic factors, but also by the processing method and the quality of equipment used.

Currently, there are three methods for extracting oil from seeds: 1) hydraulic press extraction, 2) expeller press extraction, and 3) solvent extraction. Of the three processes, solvent extraction scores highly over the other two methods, and has the following advantages: 1) maximum oil recovery, 2) lower working costs, 3) cheaper prices for end users, 4) production able to meet demand, 5) extracted oil has less sediment, and 6) solvent loss is low (Pon Pure Chemical Group 2018). Solvent or chemical extraction using n-hexane has been found to be a highly effective method of oil extraction because of its consistent performance and high oil yield. Consequently, it is the most common method (Bhuiya et al.

2015). Solvent methods have been developed in many countries and have proven to produce high oil content. Due to the many advantages of solvent extraction, this process needs to be developed further in Indonesia.

11.3.2 Oil content of trees from Ujung Kulon National Park

Analyses of pongamia oil from 48 parent trees from the same provenance (Ujung Kulon National Park) showed the oil content variance of trees or families to be highly significant (Table 4). The significance of family variance observed in this study indicates that there is significant potential for increasing gains through breeding programmes.

Variance in oil content of seed from 48 individual parent trees from the Ujung Kulon National Park provenance (mean and rank) is presented in Table 5. The oil content of seeds

Table 4. Analysis of variance of oil content between individual trees

Source of Variance	df	Sum of Square	Mean of Square	F Value	Pr > F
Tree	47	2093.85	46.5501**	4.00	<.0001
Error	78	868.55	11.1352		
Total	125	2962.40			
		R-Square	Coef. Variance	Root MSE	Mean
		0.70	9.81	3.33	34.01

Table 5. Mean oil content (%) for individual trees

Rank	Tree No.	Oil Content	Rank	Tree No.	Oil Content	Rank	Tree No.	Oil Content
1	16	44.68	17	15	34.95	33	19	31.96
2	7	43.93	18	9	34.87	34	14	31.91
3	44	43.64	19	27	34.55	35	33	31.56
4	11	42.44	20	21	34.52	36	25	30.83
5	10	40.95	21	41	34.05	37	50	30.82
6	38	40.10	22	26	34.01	38	48	30.82
7	8	40.02	23	20	33.76	39	22	30.60
8	30	38.47	24	29	33.72	40	49	30.51
9	18	37.61	25	23	33.52	41	40	30.47
10	46	37.00	26	24	33.50	42	28	30.41
11	6	36.57	27	12	33.21	43	39	29.66
12	31	36.25	28	13	32.94	44	45	29.46
13	36	35.43	29	42	32.64	45	17	29.45
14	32	35.12	30	3	32.42	46	4	29.27
15	1	34.98	31	34	32.35	47	2	29.22
16	35	34.97	32	5	32.23	48	47	26.61

from these parent trees averaged 34.01%, and ranged from 26.61% to 44.68%. These results clearly show the potential of pongamia to provide oil content of 40% when using solvent extraction, as reported in several countries. The oil content was higher than the oil content of seed using the same method observed in 45 tree accessions from three provinces in southern Thailand, where oil content varied from 26.65% to 33.12% (Panpraneecharoen et al. 2014) and was also higher than oil content in various studies from other countries (Meher et al. 2008; Dwivedi et al. 2011; Razal et al. 2012; Arpiwi 2013; Rahangdale et al. 2014).

The success of any tree improvement programme largely depends on the breeding strategy and the selection practices used to increase the expected genetic gain (Zobel and Talbert 1984). Improvement programmes begin by selecting trees in natural stands or unimproved plantations based on their phenotypic values. Selected trees are then mated, and their progenies are established in such a way that they can be used as a source of selection for the next generation of improvement (Burdon and Shelbourne 1972; Namkoong et al. 1988). Findings and the advantages of *Pongamia pinnata* indicate it is a viable species with significant potential for bioenergy production, and for forest rehabilitation and land restoration programmes in Indonesia.

11.4 Conclusion

Pongamia pinnata is a potential bioenergy species with oil content potential of up to 44.68% from the best provenance using a solvent extraction process. Study findings show that genetic factors, extraction machines and method of extraction can all influence *pongamia* oil production. Improvements to pongamia trees for biofuel, based on the oil content potential of trees from the best provenance, could produce genetically improved seed to increase oil content productivity. The quality and genetic diversity of the seed source is also extremely important for industrial plantation forest programmes for bioenergy and land restoration in Indonesia.

For future research, variance between parent trees (families) in pongamia oil content will be used to establish progeny tests in several sites. Tested progenies will gradually be converted into seedling seed orchards through combinations within plots and between families until only seed-producing trees remain to produce genetically improved seed.

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CHAPTER 12

Calophyllum inophyllum

A viable prospect for green energy and landscape restoration?

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Abstract: Indonesia has approximately 14 Mha of degraded lands. These lands have potential for growing biofuel species to meet needs for energy security, income generation and land restoration. One promising species, *Calophyllum inophyllum*, is suitable for growing on 5.7 Mha of degraded land in Indonesia, and could contribute to green energy production and restoration of this degraded land. During its early growth stage, the species can grow by up to one metre per year and is tolerant to harsh environmental conditions. Its seeds provide high levels of non-edible oil, thus making it ideal for biodiesel production. In addition, waste and by-products from the biodiesel production process can be used as raw materials in the pharmaceuticals and cosmetics industries, and as compost for soil enrichment. Growing various cash crops together with *Calophyllum inophyllum* in agroforestry systems can provide extra income for farmers, thus creating added value for *Calophyllum inophyllum* cultivation.

Keywords: *Calophyllum inophyllum*, biofuel, income, land restoration, waste utilization
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12.1 Introduction

Land degradation has become a serious problem in many tropical countries due to population growth and rapid economic development. The Government of Indonesia has introduced a number of initiatives to reverse land degradation, including community and social forestry schemes, and aims to restore 14 million hectares of degraded land and 2 million hectares of degraded peatlands by 2030 (MoEF 2018). Restoration of degraded landscapes through natural regeneration, afforestation, reforestation, agroforestation and climate smart agriculture (Lamb et al. 2005; Roshetko et al. 2007; Chazdon and Guariguata 2016) can provide opportunities to reverse biodiversity loss and enhance the delivery of ecosystem services (Rahman et al. 2018). Around 8.9 million hectares (Mha), or 53% of degraded lands identified in Indonesia, have potential for growing biofuel species such as *Calophyllum inophyllum* (5.7 Mha), *Pongamia pinnata* (4.4 Mha) and *Reutealis trisperma* (3.8 Mha) (Jaung et al. 2018).

Calophyllum inophyllum, known locally as '*nyamplung*', is ideal for producing biodiesel. It produces non-edible seeds will high kernel oil content, which can be harvested without the need to cut down trees. The species is tolerant to harsh environmental conditions and requires little maintenance in its cultivation. In Indonesia, it has a wide natural distribution from Sumatra in the west to Papua in the east, and from Java in the south to Kalimantan in the north (Leksono et al. 2014). Plantations of *C. inophyllum* in Indonesia, such as those in Wonogiri (Central Java), Gunung Kidul (Yogyakarta), Lasem (East Java), Pangandaran (West Java) and West Bali (Bali) show it is possible to combine the species in intensive silviculture and agroforestry systems (Leksono et al. 2014).

During biodiesel production processes, depending on the feed stock used, up to 50% of produce constitutes residues (Leksono et al. 2014). These include wastewater, minerals, resins, strained solids, and glycerine. If not properly processed and utilized, these residues can be harmful for the environment and for human health. *C. inophyllum* residues can easily be used to maintain the environment and can enhance the economic viability of biodiesel production processes (Leksono et al. 2017).

In recent decades, the global energy crisis and increasing demand for biofuel has prompted research into the advantages of *C. inophyllum*. This paper provides an overview of the species and its applications in green energy production and landscape restoration. It describes plant growth, biofuel content, economic potential from combinations with other commodities in agroforestry systems, and the usefulness of its by-products when used for biodiesel production.

12.2 Landscape restoration

Successful landscape restoration depends not only on the rehabilitation of biodiversity and ecosystems, but also on the choice of species used, their location in the landscape, and how they can help fulfil local people's needs (Lamb et al. 2005). Equally, for a landscape to be sustainable, the production of food and energy should coexist alongside biodiversity (Tilman et al. 2009). Perennial bioenergy crops can be planted to restore degraded or marginal lands that would otherwise be costly to restore (Lemus and Lal 2005; Tilman et al. 2009). In Indonesia, *C. inophyllum* has significant potential for the restoration of approximately 5.7 Mha of degraded lands. These lands are predominantly in Sumatra (2.7 Mha), though smaller areas have been identified in the Java and Bali regions (0.08 Mha) (Wiraguna et al. unpublished).

C. inophyllum can grow in hot temperatures. However, it is not suited to high elevations, cold regions, or very dry conditions (Prabakaran and Britto 2012). The species tolerates light to medium soils, i.e., sand, sandy loam, loam and sandy clay loam, but can also grow in soils with impeded drainage or seasonal inundation. It also tolerates calcareous rocky and saline soils (Atabani and Cesar 2014). It is a hardy tree, native to tropical coastal areas and can withstand high winds, salt spray and drought. Due to its tolerance to harsh environmental conditions, the species has been planted in southern areas of Java for conserving coastal areas and providing windbreaks, and for rehabilitating waterlogged land and rocky calcareous soils (Leksono et al. 2010). It has also been used for rehabilitating rocky soil in Gunung Kidul, Yogyakarta Province (Leksono et al. 2017).

12.3 Species growth, and development of agroforestry practices

Young *C. inophyllum* trees can grow up to one metre in height per year for their first few years, before their growth rate slows in subsequent years. A report by Soerlanegara (1994) indicates that individual trees in *C. inophyllum* stands in Malaysia reached diameters of 50 cm at breast height in 70 years. Growth of *C. inophyllum* trees in Indonesia varies depending on population origin and land characteristics. In our study, *C. inophyllum* plantations were grouped into stands on marginal land in Gunung Kidul and mineral land in Wonogiri (Table 1). Plant spacing of 5 m x 5 m was applied to allow enough space for tree canopy growth (Leksono et al. 2015). Planting techniques that combined intensive silviculture and agroforestry systems were used (Leksono et al. 2014).

12.3.1 Plantation trials on marginal land

The characteristics of the marginal land used for *C. inophyllum* plantation trials in Gunung Kidul District in Central Java are shown in Table 1. Genetic material for the species trials were collected from eight populations from different islands in Indonesia: Padang in Sumatra, Gunung Kidul in Java, Selayar in Sulawesi, East Bali, Yapen in Papua, Dompu in West Nusa Tenggara, Ketapang in Kalimantan and Sumenep in Madura. Trials were conducted using 25 square plots with 6 replications each making 150 trees from each population source, and 1,200 trees in total (Leksono 2018).

Table 1. Characteristics of the lands used for *C. Inophyllum* plantation trials

Characteristic	Gunung Kidul*	Wonogiri*
Latitude (South) **Longitude (East)**	7°53’25” 110°32’55”	7°32’ 110°41’
Elevation (m asl)	150	141
Rainfall (mm per year)	1,809	1,878
Temperature (°C)	21–32	20–38
Soil nutrients		
N (%)	0.27–0.35	0.04–0.07
P (ppm)	2.48–6.17	1.80–4.07
K (me per 100g)	0.11–0.19	0.11–0.13
Soil texture	clay, thin solum, rocky soil	Clay

*Source: Hasnah and Windyarini 2014

Table 2. shows that after five years, all populations had survival rates similar to or higher than the local population in Gunung Kidul (≥ 69%), with rates ranging from 69% for the Padang population to 80% for Ketapang. A survival rate of 60% is normally considered satisfactory in forestry plantation programmes (Lamichhane and Thapa 2011). As our results indicate all tested populations adapting well to the trial site, all populations could be cultivated in Gunung Kidul (Leksono 2018).

However, in our trials, the heights and diameters of different populations varied quite significantly after five years (Table 2). Variations in growth traits in seedlings and germination have also been reported by Hasnah and Windyarini (2014) and Palanikumaran et al. (2015), while variations in oil content, and fruit and seed size have been reported by Hasnah and Windyarini (2014) and Leksono et al. (2014). Variability between populations has generally been attributed either to the genetic characters of source populations (Uniyal and Todaria 2003), or to influences from parent plants’ environments (Fenner 1991). Since all populations are growing at the same site, such growth variations could be attributed to genetic differences (Leksono 2018). Some genotypes are specifically adapted to marginal conditions and show strong vegetative growth during their early years. This growth can vary according to latitude, elevation, soil or rainfall differences, depending on where trees are grown (Habjorg 1972a, 1972b; Eriksson and Jonsson 1986; Sukhor et al. 1989; Luomajoki 1999; Lee et al. 2015). An analysis of 11 populations of *C. inophyllum* using DNA (RAPD) markers showed that genetic differentiation between Indonesian islands was insignificant, but differentiation was significant within populations and between individual trees (Nurtjahjaningsih and Widyatmoko 2012). Considerable variation in the performance of this species should thus be expected when exposed to different environmental conditions. Further planting of the populations recommended here should be restricted to sites similar to the trial site. Stable genotypes should also be identified across the site (Sukhor et al. 1989).

Table 2. *C. Inophyllum* growth in provenance trials on marginal land

Population	Year													
	1		2			3			4			5		
	SR	H	SR	H	D	SR	H	D	SR	H	D	SR	H	D
Padang	94	1.02	81	1.16	1.06	71	1.61	1.33	69	2.14	1.89	69	2.57	2.30
Gunung Kidul	89	1.00	77	1.44	1.47	71	1.97	1.84	71	2.54	2.59	69	3.20	3.50
Selayar	87	0.78	82	1.56	1.32	75	2.14	1.95	73	2.86	2.92	73	3.53	3.79
East Bali	86	0.87	78	1.80	1.56	70	2.38	2.21	69	3.06	3.36	70	3.90	4.42
Yapen	86	0.99	84	1.55	1.38	79	1.94	1.95	79	2.37	2.88	78	3.11	3.75
Dompu	85	0.81	80	1.43	1.24	69	1.98	1.76	70	2.56	2.55	69	3.30	3.52
Ketapang	85	0.80	86	1.75	1.29	81	2.22	2.04	80	2.98	3.39	80	3.68	3.84
Madura	82	0.69	81	1.61	1.29	72	2.16	1.94	69	2.92	3.06	71	3.65	3.88

SR = survival rate (%); H = height (m); D = diameter (cm)

Source: Leksono 2018

Table 3. Growth in a *C. Inophyllum* provenance seed stand on mineral land

PMP	Year																	
	1			2			3			4			5			6		
	SR	H	D	SR	H	D	SR	H	D	SR	H	D	SR	H	D	SR	H	D
I	98	0.45		88	2.56	0.26	90	4.62	4.85	90	6.53	743	90	8.04	10.92	73*	9.39	12.63
II	100	0.39		95	3.16	0.33	95	5.11	5.54	95	6.72	8.50	95	7.97	12.04	73*	10.35	14.32

PMP = permanent measuring plot; SR = survival rate (%); H = Height (m); D = Diameter (cm)

*after first thinning

Source: Leksono et al. 2017

12.3.2 Plantation trials on mineral land

The characteristics of the mineral land used for *C. inophyllum* plantation trials in Wonogiri, Central Java, are shown in Table 1. A total of 800 trees were planted using source material originating from Gunung Kidul. The growth rates for these trees are shown in Table 3. Over the first five years, *C. inophyllum* performed well, with a 95% survival rate. After the first thinning with 10% intensity, in year six, the survival rate fell to 73%, with a mean height of 10.35 m and diameter of 14.32 cm. In these plots, 3.25% of trees began flowered at 1.5 years after planting, increasing each year to reach an annual flowering rate of 25.71% (Windyarini and Hasnah 2014; Leksono et al. 2015).

These results are much better than seen in some other locations, where the first flowering was generally at 7–8 years after planting (Bustomi et al. 2008). *C. inophyllum* growth on mineral soil in Wonogiri exceeded growth on marginal land in Gunung Kidul. It is possible that environmental conditions in Wonogiri are more favourable for *C. inophyllum* growth than those in the places of origin (Hasnah and Windyarini 2014). The main difference between Wonogiri and Gunung Kidul is the thickness of the soil layer; at 30 cm, Gunung Kidul has a thinner soil layer than Wonogiri (Wiyono et al. 2006).

12.3.3 *C. inophyllum*-based agroforestry

Through the Yogyakarta Forest Management Unit (FMU), the Yogyakarta Special Region Government has established 25 ha of *C. inophyllum* plantations to support a biofuel processing plant in Baron Techno Park in Gunung Kidul, which has a production capacity of 500 kl per batch per day. The plantation seeds were sourced from populations in Dompu in West Nusa Tenggara Province and Purworejo in Central Java.

These plantations are managed by the Wono Lestari farmer group in Menggoran Village, Playen Subdistrict, Gunung Kidul District, using agroforestry planting techniques with maize, cassava, peanuts, soybean and fodder grass. Each 25 ha planted with these agricultural commodities can provide additional incomes for farmers with annual yields and earnings as follows:

60 tons of maize @ IDR 2,000 per kg = IDR 120 million;
60 tons of cassava @ IDR 1,200 per kg = IDR 72 million;
20 tons of feed grass @ IDR 500 per kg = IDR 20 million;
1 ton of peanuts @ IDR 3,000 per kg = IDR 3 million;
0.5 tons of soybeans @ IDR 4,500 per kg = IDR 2.25 million.

This is equivalent to total earnings of IDR 217.25 million for 25 ha, or IDR 8.69 million per ha annually (Leksono 2016).

Further, farmers practicing agroforestry systems in Wonogiri use *C. inophyllum* with various annual crops, such as paddy, peanut and maize, with honey also produced in the plantations. Over a full rotation (i.e., 35 years), economic returns from each individual crop grown with *C. inophyllum* vary. Maize and paddy can only be grown for the first six years of the 35-year cycle; after that the closure of the *C. inophyllum* canopy prevents such shade-intolerant crops from growing in the understory. Peanut production follows a similar trend; even under an optimistic scenario, its production can only continue until year eight of the rotation. However, honey production is possible from the 6th year to the 35th year of the rotation, unlike other commodities, which can only be cultivated during the early phase of the agroforestry system when *C. inophyllum* trees are still young. As the Net Present Value (NPV) of honey production can likely increase as *C. inophyllum* trees mature and produce more nectar, this particular system of integration could prove to be a highly desirable investment option for farmers in Wonogiri. If a *C. inophyllum*-based system is to have long-term environmental benefits, it should also remain socioeconomically favourable for local farmers in the long term. As *C. inophyllum* is already being cultivated in the study region, there is a positive likelihood that other farmers will adopt such systems (Rahman et al. 2018).

12.4 Biofuel content

12.4.1 Natural stands

Natural stands of *C. inophyllum* in Indonesia are widely distributed across Java as well as West Sumatra, Riau, Jambi, South Sumatra, Lampung, West Kalimantan, Central Kalimantan, Sulawesi, Maluku, West Nusa Tenggara, East Nusa Tenggara and Papua provinces (Bustomi et al. 2008; Leksono et al. 2010, 2014). Local environmental conditions in these regions vary, as shown in Table 4, producing different biofuel yields between locations and populations (Table 5).

Table 4. Environmental conditions in natural stands of *C. Inophyllum*

No.	Population	Geographical Positions	Population type	Altitude (m asl)	Soil texture	Temp. (°C)	Rainfall (mm per year)
1.	Banyuwangi (East Java)	08°26’45”South 114°20’16” East	Natural forest, along the coast	0	Sandy	23–32	1,400
2.	Cilacap (Central Java)	07°41’20” South 109°8’35” East	Natural forest, along the coast	5–8	Loamy clay	23–32	1,000
3.	Ciamis (West Java)	07°45’0.23” South 108°30’8.29” East	Natural forest, along the coast	2–5	Sandy	23–32	3,000
4.	Pandeglang (Banten)	06°08’0” South 105°50’0” East	Natural forest, along the coast	0	Sandy clay	19–32	3,100
5.	Pariaman (West Sumatra)	0°35’39” South 100°06’09” East	Natural forest, along the coast	0	Sandy	23–32	2,000
6.	Ketapang (West Kalimantan)	01°12’52,20”South 109°55’50.52” East	Natural forest, along the coast	0–15	Sandy	25–30	2,000
7.	Sumenep (Madura)	07°04’31.6” South 113°49’50.1” East	Natural forest, along the coast	2–3	Sandy	26–29	900
8.	Dompu (West Nusa Tenggara)	08°17.18’0.2 South 117°59’54.2” East	Natural forest, along the coast	0	Sandy	20–32	500
9.	Selayar (South Sulawesi)	06°09’8.2” South 120°30’51.7” East	Natural forest, hilly areas	9–35	Clayish	21–34	1,700
10.	Yapen (Papua)	01°56’04.1” South 136°21’49.4” East	Natural forest, along the coast	0	Sandy	24–30	1,500

Sources: Leksono et al. 2010, 2011

Table 5. Biofuel content of *C. Inophyllum* in natural stands

No.	Population *C. inophyllum*	Dry seed (kg)	CCO (%)	RCCO (%)
1.	Banyuwangi (East Java)	2.09	42.58	41.63
2.	Cilacap (Central Java)	2.10	40.48	37.24
3.	Ciamis (West Java)	2.00	40.00	39.60
4.	Pandeglang (Banten)	1.81	37.02	36.49
5.	Sumanep (Madura)	6.00	53.17	44.67
6.	Selayar (South Sulawesi)	6.00	50.17	40.67
7.	Padang (West Sumatra)	6.00	50.17	36.00
8.	Ketapang (West Kalimantan)*	6.00	27.50	24.50
9.	Dompu (West Nusa Tenggara)	6.00	58.33	53.00
10.	Yapen (Papua)*	6.00	37.67	22.83

*technical problems occurred during the pressing process

Source: Leksono et al. 2014

The biofuel content of several populations outside Java is higher than those on Java. The highest Crude Calophyllum Oil (CCO) and Refined Crude Calophyllum Oil (RCCO) contents are obtained from populations in Dompu District, West Nusa Tenggara, with values of 58.3% and 53.0%, respectively. Meanwhile, CCO and RCCO yields from other populations range from 50%–53% and 36%–44%, respectively. This high variation in biofuel yield between natural stand populations suggests the necessity for provenance-based selection for better yields (Leksono et al. 2014).

Several physical-chemical properties of *C. inophyllum* biodiesel meet the flash point, cetane index, cloud point, sediment and water content, copper strip corrosion at 3°C–50°C, sulphate ash, sulphur content, phosphor content, acid value, total glycerol, ester alkali, iodine value and Halphen test requirements of Indonesian National Standard SNI 04-7182-2006 for biodiesel. However, several parameters: specific gravity, kinematic viscosity, micro carbon residue, distillation at 90% volume and free glycerol do not meet this standard. This indicates the importance of improving the processing of CCO into biodiesel (Sudrajat and Hendra 2012; Leksono et al. 2014).

12.4.2 Plantations

Table 6 shows the difference between unimproved and improved *C. inophyllum* plantations in terms of biofuel production potential. The table also shows that biofuel content from the provenance seed stand in Wonogiri produced 11%–14%, 7%–9% and 7%–8% higher CCO, RCCO, and biodiesel yield, respectively, compared to the original seed source in Gunung Kidul. Soil layer thickness and soil fertility are different in the two locations (Leksono et al. 2015, 2017), and genotype and environment interaction also affects biofuel yield (Burdon 1977).

Table 6. Biofuel content of *C. Inophyllum* plantations

No.	Location	CCO (%)	RCCO (%)	Biodiesel (%)
1.	Watusipat, Gunung Kidul, Yogyakarta (Unimproved seeds, as origin source population of provenance seed stand (PSS)	50.00–50.12	46.85–47.52	28.95–29.24
2.	Wonogiri, Central Java (Improved seed – PSS 2014)	61.92–64.79	54.34–56.56	35.84–36.72
3.	Wonogiri, Central Java (Improved seed – PSS 2015)	60.16–69.07	52.46–53.63	36.10–36.74
4.	Wonogiri, Central Java (Improved seed – PSS 2016)	53.56–58.00	36.89–43.56	24.67–32.00

Sources: Leksono et al. 2014, 2017

Gunung Kidul Research Station has a *C. inophyllum* plantation of two hectares, established in 1950 by the Forest Research and Development Agency (Forda), Bogor, to rehabilitate the land. Through the natural regeneration process, the forest stand was expected to become denser with seed productivity falling with time. The stand was expected to produce seed until it reached 50 years old. The provenance seed stand in Wonogiri was established using selected trees planted with a wider spacing (5 m x 5 m) for easier harvesting (Leksono et al. 2015). Trees were selected using a breeding programme to improve forest product productivity (Burdon and Shelbourne 1972; Namkoong et al. 1988).

Reliance on raw materials from unselected natural or planted stands and the lack of improved *C. inophyllum* seed likely result in inconsistencies in *C. inophyllum* oil production and quality. As strategic breeding is one possible solution for enhancing *C. inophyllum* oil quality (Leksono and Widyatmoko 2010), a programme was started to identify initial stand potential and land properties within and between six *C. inophyllum* populations from Java (Leksono et al. 2010) and six from outside Java (Leksono et al. 2011). The establishment of provenance seed stands using genetic material for high biofuel content was the next step. The best clone in terms of high seed productivity, biofuel content, and General Combining Ability (GCA) would then be selected and reproduced through vegetative propagation in order to shorten its reproductive cycle (Leksono and Widyatmoko 2010). As with most breeding programmes, the main objective was to maximize the gain per unit time as efficiently as possible, and to provide a broad genetic base for continued progress over many generations (Zobel and Talbert 1984).

The oil content of the provenance seed stands fell in 2016 compared to the previous year (Table 6). However, CCO content (53.56%–58.00%) remained higher than in the original population (50.00%–50.12%). RCCO content and biodiesel yield that year ranged from 36.89% to 43.56% and 24.67% to 32.00%, respectively (Leksono et al. 2017). Biofuel yields could have varied at different times because the seeds were collected from open cross-pollinated fruits. Biofuel yields can also vary depending on population origin, time of collection, age of tree and processing equipment used (Sudrajat et al. 2010; Hasnam 2011).

Oil content fell by approximately 14%–16% when CCO was processed into RCCO, indicating high conversion of resin/gum in kernels (dried seed). Seeds of young fruits usually contain more gum than those of ripe fruits. RCCO is a product of degumming CCO, a process that separates oil and gum (resin). Gum content is a characteristic of *C. inophyllum* seeds. Gum, a by-product of biodiesel, contains coumarin, which has potential uses in the pharmaceuticals and cosmetics industries. Oil content verification from the provenance seed stand in Wonogiri will continue periodically to determine oil content increment stability in the provenance seed stand from the origin population in Gunung Kidul (Leksono et al. 2017).

12.5 Waste utilization and use of by-products

Several processes are involved in producing biodiesel from *C. inophyllum*: fruit crushing, seed pressing, degumming, esterification, transesterification, washing and drying (Bustomi et al. 2008; Leksono et al. 2014). Solid waste (seed shells, seed dregs) and liquid waste (resin, acid grease and glycerol) are produced in biodiesel processing, as shown in Table 7.

Table 7. By-products from biodiesel processing of *C. Inophyllum* collected from seven regions in Indonesia

No.	Population	Fruit weight (kg)	Seed shell (%)	Dry seed (kg)	Seed dregs (%)	Resin (%)	Acid grease (%)	Glycerol (%)
1.	Gunung Kidul (Yogyakarta)	20	57.5	7.3	23.34	3.15	8.22	5.21
2.	Sumanep (Madura)	20	55.0	6.0	26.67	8.50	9.83	10.67
3.	Selayar (South Sulawesi)	20	60.0	6.0	26.67	9.50	6.33	0.23
4.	Padang (West Sumatra)	20	55.0	6.0	16.67	14.17	10.83	3.00
5.	Ketapang (West Kalimantan)	20	60.0	6.0	53.33	3.00	2.67	1.67
6.	Dompu (WNT)	20	55.0	6.0	28.33	5.33	9.00	7.00
7.	Yapen (Papua)	20	57.5	6.0	26.67	14.83	2.67	1.33

Source: Leksono et al. 2017

Seed shells are the first and heaviest waste produced from various plants in biodiesel processing. Shell wastes range from 25% to 60% depending on species, e.g., *Jatropha* (25%), candlenut (30%), *Calophyllum* (55%-60%) and palm oil (60%) (Sudrajat et al. 2004; Purwanto 2011; Lempang et al. 2012; Leksono et al. 2017). Shells can be utilized in making charcoal, and can be used to make charcoal briquettes, activated charcoal and liquid smoke (Leksono et al. 2017). Compressed charcoal briquettes are considered an alternative renewable energy source due to their low environmental impact and because they make use of a waste by-product. Liquid smoke can be used to preserve food, e.g., fresh fish, meat and noodles, and is also used in rubber processing (Darmadji 2002; Gumanti 2006). *Calophyllum* shells produce high-quality liquid smoke when treated at 500°C for five hours. The yield is 45.3%, with density of 1.009 g ml-1, a phenol value of 3.95%, and an acid value of 9.47%. Safety tests have indicated that *C. inophyllum* shell liquid smoke is not toxic and is safe for food (Wibowo 2012).

C. inophyllum seed dregs are the waste left over from seed pressing. They contain high levels of rough protein (21.67%– 23.59%), which can be used as a mixer in ruminant feed (Leksono et al. 2014; Leksono et al. 2017). Another use of *C. inophyllum* seed dregs is for plant compost. Solid waste from *C. inophyllum* seeds contains the following nutrients: 2.6% total N (very high), 52.2% organic C (very high), 0.14% total P (very low), 1.03% total K (very low) and a C:N ratio of 20:26 (very high). This nutrient content meets the Indonesian National Standard (SNI) for compost (Kirana 2016).

Another by-product of biodiesel production from *C. inophyllum* seeds providing additional value is coumarin resin, a potential raw material for pharmaceuticals and cosmetics. The coumarin content produced from *C. inophyllum* seeds from various islands in Indonesia is quite high, with an average value ranging from 0.26% to 0.41%, but if after being processed into CCO, the coumarin content is higher, it can reach 1,33% (Leksono et al. 2014). Thus, *C. inophyllum* seeds have significant potential for pharmaceutical and cosmetics production (Leksono et al. 2017).

Glycerol is a by-product of the transesterification process (Leksono et al. 2017). Successful transesterification is signified by the separation of the methyl ester (biodiesel) and glycerol layers after the reaction time. Glycerol has a multitude of uses in the pharmaceutical, cosmetics and food industries. It can be sold as it is or purified for use in other industries, such as soap or detergent production (Naomi et al. 2013).

12.6 Conclusion

C. inophyllum grows in a wide range of environmental conditions. Young trees can grow up to one metre per year for the first few years, and at a slower rate in subsequent years. The species is highly adaptable, as shown by survival rates exceeding 60% when planted on marginal land in Gunung Kidul District, and 95% on mineral land in Wonogiri. Applying *C. inophyllum*-based agroforestry systems combining annual crops, such as maize, cassava, peanuts, soybeans and fodder grass, could increase farmers' incomes by IDR 217.25 million annually in Gunung Kidul, while in Wonogiri, combining *C. inophyllum* with rice, peanut, maize and honey production would provide higher earnings. *C. inophyllum* is a potential bioenergy species with CCO and RCCO content ranging from 36%–58.30% and 17%–33.8%, respectively. Improved stands could increase oil content by 11%–14% (CCO), 7%–9% (RCCO) and 7%–8% (biodiesel). In addition, the industrial waste and by-products of processing *C. inophyllum* for biodiesel could be utilized to produce products including charcoal, briquettes, liquid smoke, animal feed, compost, soaps, pharmaceuticals and cosmetics. This would increase the economic value of *C. inophyllum* cultivation, and simultaneously reduce environmental pollution.

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CHAPTER 13

Pongamia

A possible option for degraded land restoration and bioenergy production in Indonesia

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Abstract: Indonesia has 14 million ha of degraded and marginal land, which provides very few benefits for human well-being or biodiversity. This degraded land may require restoration. The leguminous tree *Pongamia pinnata* syn. *Milettia pinnata* (pongamia) has potential for producing biofuel while simultaneously restoring degraded land. However, there is limited information on this potential for consideration. This paper aims to address the scientific knowledge gap on pongamia by exploring its potential as a biofuel and for restoring degraded land in Indonesia. We applied a literature review to collect relevant information on pongamia, which we analysed through narrative qualitative and narrative comparative methods with careful compilation and scientific interpretation of retrieved information. The review revealed that pongamia occurs naturally across Indonesia; in Sumatra, Java, Bali, Nusa Tenggara and Maluku. It can grow to a height of 15–20 m and thrives in a range of harsh environmental conditions. Its seeds can generate up to 40% crude pongamia oil by weight. It is a nitrogen-fixing tree that can help restore degraded land and improve soil properties. Pongamia also provides wood, fodder, medicine, fertilizer and biogas. As a multipurpose species, pongamia holds great potential for combating Indonesia's energy demand and restoring much of the country's degraded land. However, the potential competition for land and for raw materials with other biomass uses must be carefully managed.

Keywords: Indonesia, pongamia, renewable energy, land restoration
Link: https://www.mdpi.com/1999-4907/12/11/1468
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13.1 Introduction

An ever-growing demand for energy has increased the importance of new and renewable sources of energy (Hidayat 2005; Kotarumalos 2009). Petroleum fuel is the primary source of energy used by communities in Indonesia to run their vehicles, generators and other machinery powered by combustion engines (Hidayat 2005). In recent years, Indonesia has switched from being a petroleum-exporting to a petroleum-importing country, and its own natural reserves are expected to provide alternative energy sources. As biofuel is considered an important alternative source of energy (Kotarumalos 2009), the Government of Indonesia's national energy policy supports new and renewable energy, which could provide up to 23% of national energy needs by 2025 and 31% by 2050 (Republic of Indonesia 2014).

Globally, most biofuels are currently produced from oil palm, coconut, cassava, corn, sorghum and other edible food crops, and are known as first generation biofuels (Hassan et al. 2013). Second generation biofuels use non-food crops as feedstocks and involve more advanced technologies in their production (Antizar-Ladislao et al. 2008; Pena et al. 2016). Some non-food crops, e.g., jatropha (*Jatropha curcas*), have biofuel potential but require fertile land to achieve high yields, and the resulting competition with subsistence and cash crops limits their overall production prospects (Pena et al. 2016). Therefore, there is an urgent need to identify suitable plant species that can be used as energy sources and can grow on abandoned lands, i.e., marginal or degraded lands. Pongamia (*Pongamia pinnata* syn. *Milettia pinnata*) is one such species. Its seeds are valued for their biofuel properties, and it can grow on marginal and degraded land (Kesari et al. 2010). As biofuels are produced from renewable feedstocks via photosynthesis using atmospheric CO_2, their combustion is less harmful to the atmosphere (IPCC 2012; IEA 2021). Biofuels have received much attention because, with the exception of a few unhealthy compounds found in oil cakes, they are non-toxic, renewable and more biodegradable in nature than petroleum-derived fuels [Pandey et al. 2011; Leksono et al. 2014, 2017). Toxic pollutants, such as carbon monoxide (CO), unburned hydrocarbons (UHC), and particulate matter (PM) are also significantly lower when biofuels rather than petroleum fuels are burned in compression ignition (CI) engines (Ogunkule et al. 2021). Further, an important consideration for biofuel-producing crops is their ability to grow on degraded land, as they can present a sustainable solution to the bioenergy land-use perplexity (Lewis et al. 2014).

Indonesia has around 14 million ha of degraded and marginal lands, which is of limited benefit for food production and environmental services (Ministry of Environment and Forestry 2019). The Government of Indonesia has committed to restoring 12 million ha of this degraded land in an effort to achieve climate resilience in the food, water and energy sectors (Ministry of Environment and Forestry 2016, 2018). In relation to energy production, a scientific study has revealed that 3 million ha of severely and critically degraded land is suitable for biofuel and biomass plantations (Jaung et al. 2018). Several government agencies have land restoration targets. These include the Peatland Restoration Agency or *Badan Restorasi Gambut*, which aims to restore more than 2 million ha of degraded peatlands in Riau, Jambi, South Sumatra, West Kalimantan, Central Kalimantan, South Kalimantan and Papua provinces (Lamb et al. 2010) (see Figure 1). As a potential bioenergy species, pongamia could provide an opportunity to restore degraded lands while enhancing ecosystem services (Baral and Lee 2016) and supporting local economies (Casillas and Kammen 2010; Malla 2013; Lynd et al. 2015). (The restoration of degraded areas covered with *Imperata cylindrica* (*alang-alang*) grass in Indonesia may also requires crops like pongamia that can shade out such areas and enhance ecosystem services and financial benefits.

Pongamia is a leguminous species native to Bangladesh, India, China, Pakistan, Sri Lanka, Vietnam, Malaysia, Indonesia, Japan, Fiji and Australia, and has been introduced to the United States, Puerto Rico and many African countries, including Egypt (Orwa et al. 2009). The species occurs naturally in humid and sub-tropical regions and grows well in a wide range of agro-climatic conditions (Hidayat 2005). Common names for the species include Indian beech, karum tree (English); *pongam* (Gujarati); *dalkaramch* (Tamil); *karanj, karanja, kanji* (Hindi); *kanuga* oil tree (Telugu); honge (Kannada); shuihuang pi (Chinese); day mau (Vietnamese); *kranji, malapari* (Indonesian); and *mempari* (Malay) (Bobade et al. 2012; Aminah 2017). Pongamia has been utilized traditionally as a pharmaceutical plant (Orwa et al. 2009). It is a preferred species for controlling soil erosion and binding sand dunes because of its dense network of lateral roots. It can also be productive on degraded land (Sangwan et al. 2010).

This chapter compiles information on pongamia, including its natural distribution, growth, yields, biofuel potential and land restoration capacity, to corroborate scientific understanding. It may provide a valuable resource for practitioners in planning bioenergy and restoration projects.

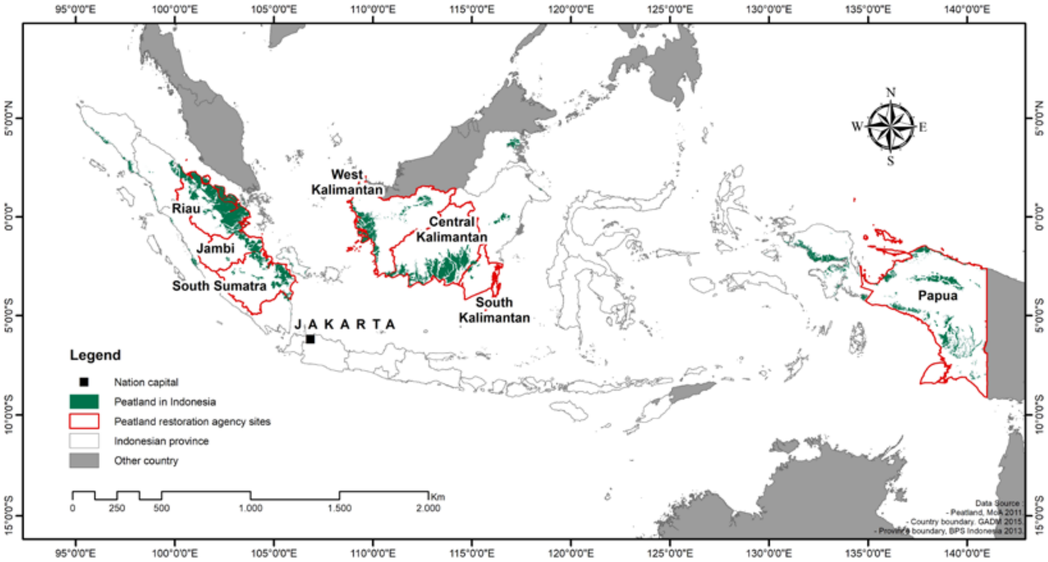

Figure 1. Distribution of peatlands and peatland restoration areas in Indonesia

Source: *Badan Restorasi Gambut* 2016

13.2 Materials and methods

This study is based on a literature review of both peer-reviewed and grey literature. The review mainly focused on four scientific areas of interest, i.e., distribution and growth, potential yield, potential biofuel, and landscape restoration capacity of pongamia. A preliminary scoping study was conducted based on a Google Scholar search targeted at finalizing key words and search phrases, and contributing to the framing of the manuscript. After finalizing key words and phrases, as well as inclusion criteria (Table 1), relevant literature was gathered using scientific research search sites, i.e., Google Scholar, Mendeley, Scopus and Web of Science. In our literature search, we only considered published scientific papers available online. At the outset of the study, we conducted a quick review of the abstracts and contents of the retrieved literature to evaluate their relevance for inclusion in further extensive reviews. After removing any duplicates, and considering the timeframe for this study, we selected 84 of the 770 pieces of literature for thorough review by considering their relevance. A basic checklist of quality criteria (i.e., clear aim and replicable methodology, accurately and reliably measured outcomes, and consistently reported findings with methodologies and empirical data provided) was used to select these 84 pieces of literature. A total of nine months from January 2018 to September 2019 (and again from June to September 2021 for revision) was required for four reviewers (one full-time and three part-time) to extract relevant data. Further supporting data was gathered from the Indonesian Ministry of Environment and Forestry (MoEF) and is presented in Annex 1 of this paper.

Table 1. Search sites, key words and inclusion criteria to generate targeted information from the literature review used in this study

Search Sites	Key Words and Search Phrases	Inclusion Criteria
Google Scholar Mendeley Scopus Web of Science	‘pongamia’ OR ‘bioenergy’ OR ‘biofuel’ OR ‘jet fuel’, ‘pongamia’ AND ‘bioenergy’, ‘pongamia’ AND ‘biofuel’, ‘pongamia’ AND ‘jet fuel’, ‘pongamia’ AND ‘oil’, ‘pongamia’ AND ‘yield’, ‘ pongamia’ AND ‘growth’, ‘bioenergy’ AND ‘Indonesia’, ‘biofuel’ AND ‘Indonesia’, ‘pongamia’ AND ‘Indonesia’, ‘biofuel’ AND ‘Indonesia’, ‘pongamia’ AND ‘land restoration’, ‘pongamia’ OR ‘land restoration’ AND ‘Indonesia’, ‘pongamia’ AND ‘nitrogen’, ‘pongamia’ OR ‘land restoration’ AND ‘nitrogen’, ‘pongamia’ AND ‘benefit’, ‘pongamia‘ AND ‘potential’, ‘pongamia’ AND ‘wood’, ‘pongamia’ AND ‘medicine’, ‘pongamia’ AND ‘landscape’, ‘land tenure’ AND ‘Indonesia’, ‘land tenure’ AND ‘tree planting’, ‘land tenure’ AND ‘pongamia plantation’	Evidence-based information on pongamia, i.e., distribution, growth, yields, biofuel potential, land restoration capacity

Note: ‘Millettia’ is a synonym of ‘Pongamia’, and was mistakenly overlooked as a search word. This may have resulted in the omission of some relevant articles.

Relevant information was carefully compiled point-by-point, and scientific interpretations were made by using narrative qualitative and narrative comparative analysis methods, including tables and figures (Riessman 1993; Smith 2000; Samsudin et al. 2020). (Narrative analysis methods are characterized by perspective and context, which deal with points of view regarding what has happened, and describing what may be significant in the near future (Gee 2021). They simply provide meaning and coherence to, and perspective on, experience and knowledge (Bruner 2020). The analysis process was designed to scrutinize relevant concepts in a transparent and subjective way, following the objective of this paper and the inclusion criteria (Table 1), i.e., the growth, distribution, yield and biofuel production potential, and landscape restoration capacity of pongamia. Careful attention was paid to a more discursive interpretation and to representing a view of reality through a process of decontextualization and recontextualization with appropriate scientific order as presented in Section 3 below. It is also important to mention that some terms in this manuscript are stated in general without having precise quantification (e.g., pongamia growth rates), which reflects the original literature source

13.3 Results and discussion

13.3.1 Potential of pongamia as a biofuel species

Distribution

Pongamia grows naturally across the Indonesian archipelago, mostly in Berbak National Park in Jambi Province, Sembilang National Park in South Sumatra Province; Berikat Gulf in Bangka Belitung Province; Ujung Kulon in Banten Province; Batu Karas, Pangandaran in West Java Province; Alas Purwo National Park and Baluran National Park in East Java Province; Senipah, Samboja, Sekerat and Tanjung Batu in East Kalimantan Province; Lovina in Bali Province; and Sembelia in East Lombok, West Nusa Tenggara Province. It can also be found in the western part of Seram island, Maluku Province (Figure 2) (Djam’an 2009; Sidiyasa et al. 2012; Aminah et al. 2017; Jayusman 2017). Pongamia has many local names in Indonesia, including *malapari* (Simeulue), *mabai* (Bangka), *kipahanglaut* (East Java), *bangkongan* and *kepik* (Java), *kranji* (Madura), *marauwen* (Minahasa, Sulawesi), *hate hira* (Ternate) and *butis* and *sikam* (Timor) (Djam’an 2009).

Pongamia grows well naturally in lowland forests on calcareous soils, in rocky coastal areas, along the edges of mangrove forests, and along streams and estuaries. It is a hardy woody plant and can survive temperatures ranging 5 to 50°C and elevations up to 1,200 m (Sidiyasa et al. 2012; Ramachandran and Radhapriya 2016). It grows well in both full sunlight and partial shade and can grow in most soil types from stony through sandy to clay. Although it is salinity tolerant, it does not survive well in dry sands (Csurhes et al. 2016). Studies have found pongamia to have potential for growing as a restoration species in highly degraded forest areas (Ramachandran and Radhapriya 2016) and on land which

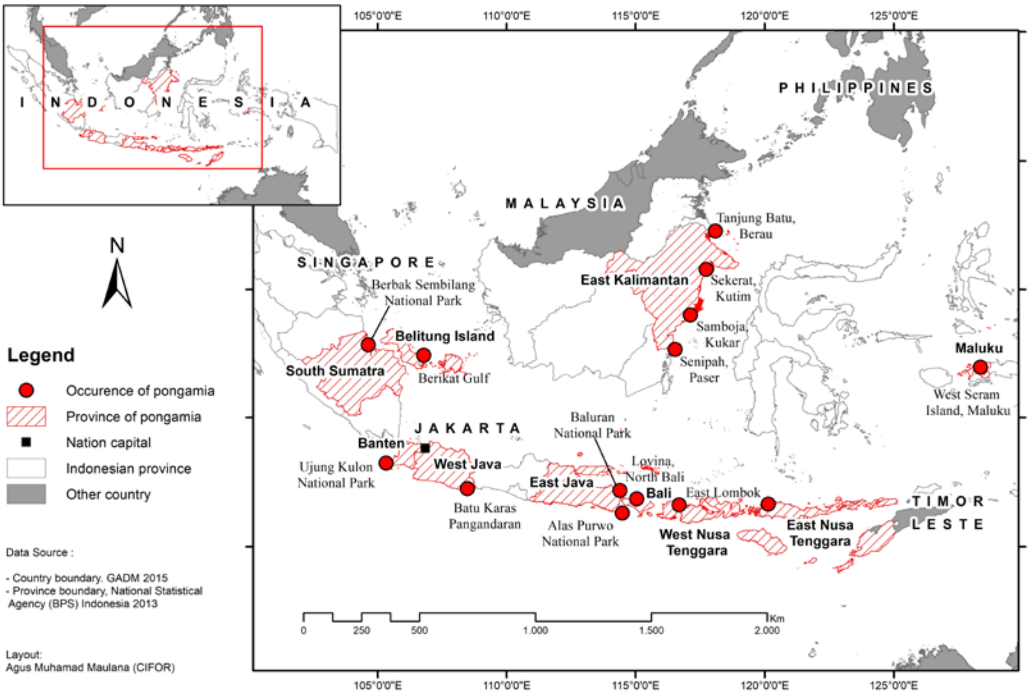

Figure 2. Natural distribution of pongamia in Indonesia

Sources: (Djam'an 2009; Sidiyasa et al. 2012; Aminah et al. 2017; Jayusman 2017)

has been degraded physically, chemically and biologically due to mining operations (Agus et al. 2017). Pongamia plantation trials in a hot, dry area with limestone soil at Bukit Jimbaran, Bali showed 100% survivability of plants two months after planting without irrigation. Trial plants also showed vigorous growth in height (7.5–13.60 m), stem diameter (20.70–63.69 cm at breast height) and numbers of compound leaves (crown width 6.00–20.0 m) (Arpiwi et al. 2018), indicating pongamia's adaptability to the hot, dry conditions associated with marginal land. Similarly, another study (Aminah and Syamsuwida 2017) observed survival rates ranging 88 to 100% with average height of 83.75 cm and diameter of 0.85 cm six months after planting in Java. In a trial plot on degraded peatland in Buntoi Village, Pulang Pisau District, Central Kalimantan Province, pongamia trees started flowering 1.5 years after planting (Figure 3) (Maimunah et al. 2018). Another study showed four-month-old pongamia seedlings demonstrating tolerance to 200 and 150 mM NaCl saline drain and saline waterlogged conditions respectively (Arpiwi et al. 2013).

Figure 3. Pongamia tree flowering 1.5 years after planting in a trial plot in Buntoi, Pulang Pisau, Central Kalimantan

Pongamia is a semi-deciduous tree, the seeds of which contain non-edible oil, which can be processed into biodiesel. However, recent technological advances have allowed the seeds to be processed as food. It is a forest tree, demands only low levels of moisture and is therefore drought resistant, and needs only minimum input and management to grow well (Bobade and Khyade 2012; Dwivedi and Sharma 2014) . It can reach heights of 15–20 m and has a large and wide crown (Bobade and Khyade 2012). It grows very rapidly and reaches its full height and maturity within 4–5 years (Duke 1983). Pongamia can be propagated by generative or vegetative means. It can be propagated vegetatively from cuttings and root suckers (with new plants growing from lateral roots of the parent tree) (Orwa et al. 2009). Pongamia is also propagated from seeds in nursery beds or polybags and via in-situ sowing of seeds in plantations (Scott 2008; Kesari and Rangan 2010). It has also been reported that seeds stored for three months or more result in lower germination and plant vigour (Scott 2008). Seeds take approximately one week to germinate and around 85% of seeds do so with appropriate nursery management. Study findings have also indicated a direct relationship between seed size and germination efficiency, but only for fresh seeds (Kesari and Rangan 2010). The long-term viability of pongamia trees also depends on appropriate pruning practices. Information on pongamia growth rates from four trial sites is presented in Annex 1.

Yields

Pongamia produces large quantities of seeds. However, yields vary according to soil and climatic conditions, as well as management practices (Dwivedi et al. 2011; Chandrashekar et al. 2012; Murphy et al. 2012; Bobade and Khyade 2012; Csurhes and Hankamer 2016; Garg et al. 2017). There is limited information on pongamia seed yields in Indonesia, with most literature coming from India and Australia [Dwivedi et al. 2011; Murphy et al. 2012; Abadi et al. 2016; Garg et al. 2017). This is because pongamia grows naturally or in plantations in a wide range of regions in India, while pongamia is cultivated extensively in Queensland, Australia (Kesari and Rangan 2010; Murphy et al. 2012).

Pongamia can produce 9 to 90 kg of seeds annually per adult tree in India, equivalent to a potential yield of between 900 kg and 9,000 kg per hectare (Dwivedi et al. 2011; Bobade and Khyade 2012). This differs slightly from yields of between 20 kg and 80 kg per tree reported in Australia (Abadi et al. 2016). Another report noted average annual seed production of 20 kg per tree in Australia (Murphy et al. 2012). Another study (Arpiwi et al. 2014) reported seed yield of pongamia trees improving significantly in the northern part of Western Australia after the introduction of *Apis mellifera* beehives (up to 4.9 kg per one-year-old tree), as bees are effective pollinators for pongamia. Incorporating *Apis mellifera* bees into pongamia plantations could be a win–win solution for successful pongamia pollination and honey production.

In Bangladesh, young pongamia (15 years old or younger) produced more than 25 kg of seeds per tree annually. However, yields increased as trees grew older, i.e., annual yields of more than 100 kg for 20-year-old trees (Rahman et al. 2014). A trial plot in Parung Panjang,

Figure 4. A pongamia-based agroforestry system in Parung Panjang, West Java, Indonesia.

West Java, Indonesia showed that pongamia trees as young as eight years old cultivated in an agroforestry system can provide 3.80 kg of seeds per year (Figure 4, Appendix A). Pongamia trees can live for up to 100 years, can produce seeds every year, and require minimal maintenance once they reach 30 years old (Rahman et al. 2014).

Biofuel production potential

The most useful product from pongamia is biodiesel. Biodiesel is produced by the transesterification of vegetable oils or animal fats using alcohol (methanol or ethanol) and a catalyst (e.g., potassium hydroxide (KOH) or sodium hydroxide (NaOH) (Rahman et al. 2014). The biodiesel produced is a clean burning fuel that has no sulphur emissions and is non-corrosive (Chincholkar et al. 2005). At low pressures and temperatures, transesterification produces 80% methyl ester, and 20% glycerin as by-products (Bobade and Khyade 2012). The major fatty acids in crude pongamia oil are oleic (51%), linoleic (19%), palmitic (11%), stearic (6%), linolenic (4.5%) and behenic (4.5%) (Arpiwi et al. 2013). Pongamia oil extracts exhibit good chemical properties and could be used as good biodiesel feedstock (Bobade and Khyade 2012). Fatty acid methyl ester from pongamia and other potential biodiesel plants such as *Azadirachta indica*, *Calophyllum inophyllum* and *Jatropha curcas* meet the major specifications of biodiesel standards required by American and European standards organizations (Azam 2005)

During the past few decades, pongamia oil has attracted considerable attention as a potential renewable, biodegradable, eco-friendly, non-toxic fuel (Bobade and Khyade 2012) and as being economically viable (Abadi et al. 2016). Studies have determined oil yield and properties with 1,000 kg of pongamia seeds yielding 270–300 kg of crude pongamia oil

(Chandrashekar et al. 2012). In other studies, oil yield was reported to reach up to 35% by weight (Ahmad et al. 2009; Bobade and Khyade 2012), with some reports showing yields of up to 40% (Nabi et al. 2009; Murphy et al. 2012). Crude pongamia oil needs further processing (transesterification) to give methyl esters. Around 85–90 L of biodiesel and 15–16 L of glycerin (considered a by-product) can be obtained from 100 L of crude pongamia oil by transesterification (Chandrashekar et al. 2012).

Meanwhile, other studies have found approximately 4 kg of pongamia seeds being required to produce one litre of crude pongamia oil, which in turn could yield 0.896 L of biodiesel (Patil et al. 2015). The major cost of biodiesel production from pongamia is the feed stock, which can account for 60% of total production costs, followed by chemical costs for transesterification at 17%, and operating costs at 10% (Doddabasawa 2009). Therefore, high seed yield is the key to successful pongamia biodiesel production. A study on the economic viability of pongamia biodiesel production in Fiji (Prasad and Singh 2020) showed the levelized cost of biodiesel to be USD 1.44 per litre and the benefit–cost ratio to be 1:06. Tables 2–4 below detail properties of crude pongamia oil. It is worth noting that pongamia can yield a considerable volume of biodiesel in comparison with other biofuel-producing species (see Figure 5). However, the oil content of pongamia may vary depending on seed source, processing methods (i.e., hydraulic press, mechanical press or solvent extraction) and equipment used (Table 5).

Table 2. Physio-chemical properties of crude pongamia oil

Property	Unit	Value
Color	-	Yellowish red
Density	g cc^{-1}	0.924
Viscosity	mm^2 s^{-1}	40.2
Acid value	mg KOH g^{-1}	5.40
Iodine value	-	87
Saponification value	-	184
Calorific value	Kcal kg^{-1}	8742
Specific gravity	-	0.925
Unsaponifiable matter	-	2.9
Flash point	°C	225
Fire point	°C	230
Cloud point	°C	3.5
Pour point	°C	-3
Boiling point	°C	316
Cetane number	-	42
Copper strip corrosion	-	No corrosion observed
Ash Content	%	0.07

Source: Bobade and Khyade 2012

Table 3. Fatty acid composition of crude pongamia oil

Fatty acid (%)	Molecular formula	Percentage	Structure
Palmitic acid	$C_{16}H_{32}O_2$	11.65	$CH_3(CH_2)_{14}COOH$
Stearic acid	$C_{18}H_{36}O_2$	7.50	$CH_3(CH_2)_{16}COOH$
Oleic acid	$C_{18}H_{34}O_2$	51.59	$CH_3(CH_2)_{14}(CH{=}CH)COOH$
Linoleic acid	$C_{18}H_{32}O_2$	16.64	$CH_3(CH_2)_{12}(CH{=}CH)_2COOH$
Eicosanoic acid	$C_{20}H_{40}O_2$	1.53	$CH_3(CH_2)_{18}COOH$
Dosocasnoic acid	$C_{22}H_{44}O_2$	4.45	$CH_3(CH_2)_{20}COOH$
Tetracosanoic acid	$C_{24}H_{48}O_2$	1.09	$CH_3(CH_2)_{22}COOH$

Source: Bobade and Khyade 2012

Table 4. Properties of pongamia methyl ester

Property	Unit	ATSM Test Method	Pongamia Biodiesel	Diesel
Density	g cc^{-1}	D1498	0.860	0.824
Calorific value	Kcal kg^{-1}	D240 / D4868	3,700	4,285
Cetane number	Number	D613	41.7	49
Acid value	Mg $KOHg^{-1}$	D664	0.46	0.26
Iodine value	Number	D1510	91	-
Water and sediments	% vol. max	D2709	0.005	-

Source: Bobade and Khyade 2012

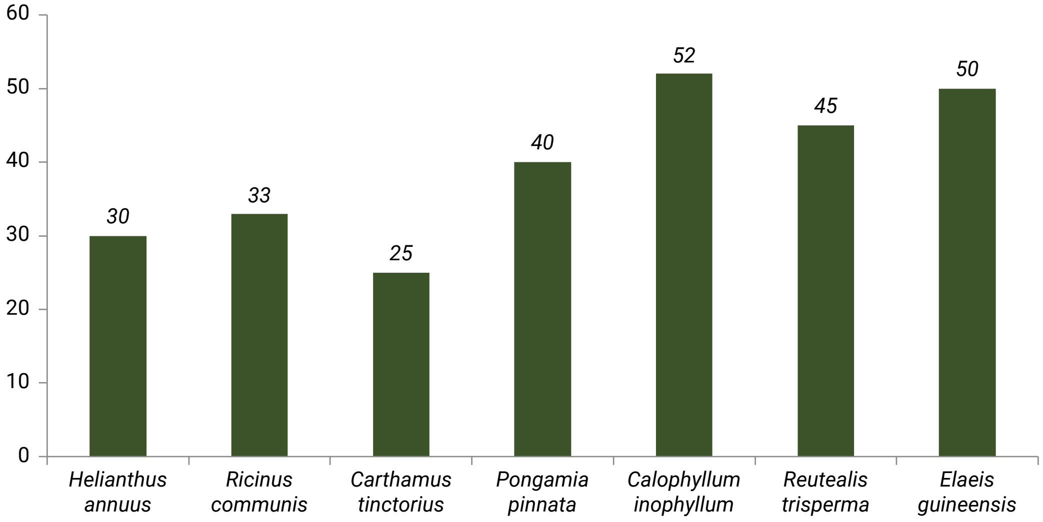

Figure 5. Average percentages of crude oil yielded by pongamia and other biofuel species (Bobade and Khyade 2012)

Table 5. Pongamia oil content from different seed sources and extraction methods

No.	Oil content (%)	Method	Equipment	Seed/seed source	Reference
1.	15.44–15.82	Mechanical press	Simple screw expeller press	Bulk seed/Banten, Indonesia	Jayusman 2017
2.	15.92–19.60	Mechanical press	Fabricant screw expeller press	Bulk seed/Banten, Indonesia	Hasnah et al. 2020
3.	14.25–14.67	Mechanical press	Simple screw expeller press	Bulk seed/West Java, Indonesia	Jayusman 2017
4.	13.05–13.23	Mechanical press	Simple screw expeller press	Bulk seed/East Java, Indonesia	Jayusman 2017
5.	24.00–26.00	Mechanical press	Simple screw expeller press	Bulk seed/India	Meher et al. 2008
6.	27.34–39.26	Solvent extraction	Soxhlet extractor	Bulk seed/Banten, Indonesia	Hasnah et al. 2020
7.	26.61–44.68	Solvent extraction	Soxhlet extractor	Individual seed/ Banten, Indonesia	Hasnah et al. 2020
8.	26.30–32.00	Solvent extraction	Soxhlet extractor	Bulk seed/Bali, Indonesia	Arpiwi et al. 2018
9.	28.00–31.00	Solvent extraction	Soxhlet extractor	Bulk seed/Bali, Indonesia	Arpiwi et al. 2017
10.	27.00–39.00	Solvent extraction	Soxhlet extractor	Bulk seed/India	Meher et al. 2008
11.	33.31–39.01	Solvent extraction	Soxhlet extractor	Bulk seed/Madhya Pradesh, India	Rahangdale et al. 2014
12.	28.18–41.32	Solvent extraction	Soxhlet extractor	Bulk seed/Carmen, Philippines	Razal et al. 2012
13.	33.00–40.30	Solvent extraction	Soxhlet extractor	Bulk seed/ Queensland and Northern Territory, Australia	Arpiwi et al. 2013

Pongamia for bio-jet fuel

One potential product from pongamia is bio-jet fuel. Most aircraft are fuelled by conventional jet fuel, which is non-renewable, costly and emits large amounts (80%) of carbon, e.g., one ton of conventional jet fuel emits 0.8 tons of carbon when burned (Hendricks et al. 2011). Therefore, the aviation industry is looking for renewable jet fuels (Hendricks et al. 2011). However, compared to other industries, aviation has a limited range of alternative renewable fuel options that can replace fossil fuels. Bio-derived jet fuel could be a viable alternative for aviation industries (Graham et al. 2011). *Camelina sativa*, *Jatropha* spp., *Elaeis guineensis* and algae have already been used to produce fuel for several test flights. Pongamia oil has yet to be tested, but has significant potential (Murphy et al. 2012), as it can abate 43% of greenhouse gases on a lifecycle basis (Cox et al. 2014).

13.3.2 The potential of pongamia for land restoration

Nutrition enhancement for degraded land

Degraded land is land that has lost its productivity (Lamb 2010). Such land often has low soil nutrient content, low productivity, suffers from erosion, and is unsuitable for growing crops. There are two main ways of restoring degraded land: (i) physical, technical or engineering restoration; or (ii) biological restoration (Ahirwal et al. 2016).

Pongamia trees have several benefits for restoring degraded land. Studies have shown five-year-old pongamia plantations having carbon sequestration potential of around 13.43 tons per ha (Bohre et al. 2014; Edrisi and Abhilash 2016). Pongamia is capable of withstanding drought stress, can grow on saline soils, and needs little topsoil as it has a dense network of lateral roots and long thick taproots. Pongamia plantations can help alleviate compaction and crusting (Lal 2010). It is a sturdy plant with no special nutritional requirements and can grow in extreme environmental conditions. It is tolerant to soil sodicity, pH imbalances, high temperatures, heavy metal contamination, drought and poorly drained soils. Consequently, pongamia can achieve phytostabilization, i.e., the long-term stabilization and containment of pollutants (Juwarkar and Singh 2010; Singh 2013). Iron, chromium, copper, manganese and magnesium in fly ash dykes have been phytostabilized by establishing pongamia plantations on the dykes (Singh 2013). Therefore, establishing pongamia biofuel plantations on degraded land can be a win–win solution for energy production and land restoration, especially compared to *Elaeis guineensis* (oil palm), where links to deforestation are a worldwide concern (Balooni and Singh 2001; Juwarkar and Singh 2010; Lal 2010; Ahirwal 2016).

Nitrogen fixation

Chemical nitrogen fertilizer is widely used for growing crops. However, it is costly, and its production causes high levels of greenhouse gas emissions (Kesari et al. 2013). The restoration of degraded land also requires the stabilization of its nitrogen content. Pongamia is a leguminous tree that fixes nitrogen, while also producing raw material for biofuel (Chaukiyal et al. 2000; Samuel et al. 2013). In contrast, other common biofuel crops, such as canola, sugarcane, sweet sorghum, maize and woody trees (e.g., eucalyptus and willow), deprive soils of nitrogen rather than increasing nitrogen content (Samuel et al. 2013). Pongamia fixes nitrogen throughout its life (Samuel et al. 2013). A study of the phenotypic characteristics of rhizobia isolates from pongamia showed isolates growing well at temperatures ranging 29 to 39°C, within pH levels 7 to 9, and tolerating less than 1% salinity. It also showed isolates from Rhizobium and Bradyrhyzobium genera being effective microsymbionts under controlled conditions

(Arpiwi et al. 2013). Relative effectiveness of the symbiosis between pongamia as a host and rhizobia is determined by dividing shoot dry weight of plants inoculated with rhizobia isolate by shoot dry weight of plants treated with nitrogen fertilizer expressed as a percentage of weight (Fterich et al. 2014). By using this method, the highest relative effectiveness of rhizobia isolates was 85.9% (Arpiwi et al. 2013).

Another study showed that nodules of pongamia formed on seed-derived seedlings within four weeks with visible nodulation and established symbioses by eight weeks at 28°C. The nodules produced by these strains were uniformly filled with bacteroid zones (Biswas and Gresshoff 2014). Pongamia nodules can actively fix nitrogen as demonstrated by quantification by gas chromatography of ethylene in acetylene reduction assays, where C_2H_2 (acetylene) serves as a substrate for bacterially encoded nitrogenase (Balooni and Singh 2001). Therefore, cultivating pongamia together with agricultural crops has the potential to produce favourable agricultural yields.

Other services provided by pongamia

Restoring degraded land using pongamia could also provide a range of services to benefit local communities and nature by enhancing ecosystem functions (see Table 6). Such services could be enhanced with appropriate pongamia plantation design by counting costs and benefits as well as trade-offs and synergies associated with different options in specific locations, e.g., various understory crop combinations considering local economic, cultural and environmental values (Figure 3).

13.3.3 Community involvement

As stakeholders, local communities can be directly affected by fuel shortages, and their potential contributions (Rahman et al. 2017) should be taken into account during pongamia cultivation processes. Such contributions could be overseen through local technical and administrative capacity building (Ostrom 1990; Watts and Colfer 2011) to strengthen pongamia cultivation at the landscape level. Community involvement could also enhance local incomes, innovative spirit, technical proficiency and enthusiasm through the distribution of degraded land in areas surrounding settlements to communities for pongamia cultivation, or by villagers using their own degraded land for the same purpose (Nawir and Murniati 2007; Rahman et al. 2017). It may also increase transparency and accountability for all parties (local communities, government and investors), foster a sense of responsibility and encourage support and mutual interest for land restoration efforts (Basria and Nabihab 2014).

Table 6. Pongamia tree products and their various uses

Attributes	Important uses	References
Wood	Pongamia logs serve as the raw material for wood flour as lignocellulosic filler that can be further processed to produce wood–plastic composites.	Islam and Bari 2016
	Pongamia wood is useful for making tool handles, combs, cabinets, cartwheels, posts, agricultural implements and paper pulp	Orwa et al. 2009, Dwivedi et al. 2011
	Pongamia wood is used as fuelwood	Dwivedi et al. 2011
Medicine	Almost all parts of pongamia trees are used in folk medicine: Juice from the roots blended with coconut milk is used to treat gonorrhea. Stem bark extract has sedative and antipyretic qualities and reduces enlarged spleens. Juice from the leaves is used to treat diarrhea, colds and coughs, and to relieve rheumatism. The fruits are used to treat abdominal tumors. The seed is used to treat keloid tumors, skin ailments and hypertension, and as an expectorant for bronchitis and whooping cough. The flowers are used to treat certain diabetic conditions. The oil is used to treat leprosy, chronic fever, skin diseases and rheumatism	Orwa et al. 2009, Sangwan et al. 2010
	A crude decoction of pongamia leaves is used as an antidiarrheal with efficacy against cholera	Brijesh et al. 2006
Fodder	The leaves are commonly used for cattle feed and, less so, for goat feed, and are a valuable source of fodder in arid regions. Seed residue, presscake and seedcake contain much protein and are used for poultry feed; but should not exceed 75% of feed as they contain several toxic compounds	Duke 1983, Orwa et al. 2009, Dwivedi et al. 2011
Fertilizer and biogas	The seedcake and leaves are used as fertilizer. Seedcake can generate biogas in household biogas generators	Chandrashekar et al. 2012, Chandrashekar et al. 2017
Biodiversity restoration	Pongamia trees can restore biodiversity by improving soil quality, controlling erosion, and enhancing vegetation cover at the landscape level (including in sandy, heavy clay, rocky and waterlogged areas)	Kesari and Rangan 2010, Sangwan et al. 2010, Herman 2016, Herman et al. 2013, Modi and Dudani 2013, Shirbhate and Malode 2012, Dutta and Agrawal 2003
Other services	Pongamia trees serve as windbreaks, are fire tolerant, and are ornamental trees. The oil is used as a lubricant, as a leather dressing, and for manufacturing soap, varnish and paint. The flowers are a good source of pollen and nectar, yielding a dark honey. The bark is used to make rope. Pounded and roasted seeds used to be utilized as a fish poison. Dried leaves are useful to store with grain to repel insects	Kesari and Rangan 2010, Orwa et al. 2009, Dwivedi et al. 2011, Azam et al. 2005, Ahmad et al. 2009, Pranowo and Herman 2016, Herman et al. 2013, Wulandari et al. 2015, Atabani and César 2014, Bridgemohan and Bridgemohan 2014, FAO 2010, Bustomi et al. 2009, Akinerdem and Öztürk 2008, Sumathi et al. 2008

13.4 Other considerations

To restore forestland, it has to be a biodiversity-rich, self-regenerating system, consisting of a microclimate and a wide variety of plants and animals in mutual coexistence (Rojas 2012). Monoculture plantations may not provide as high levels of biodiversity as forest, and require ongoing human intervention including the use of herbicides and pesticides during land preparation (Scott et al. 2008; Nagarjun and Suryanarayana 2014; Usharan et al. 2019; Kumari et al. 2020). Profitable pongamia plantations might also become a new driver of land clearing and an indirect cause of deforestation, especially where land tenure is not clear, as witnessed in various countries (Angelsen and Kaimowitz 2004; Rojas 2012). Secure land tenure is crucial for the successful implementation of tree-planting activities (Tomich et al. 2002; Rahman et al. 2014). If local communities have insecure rights to use land and to harvest produce from trees, they are less likely to tend trees. When farmers lack secure land titles, they are deprived of access to the credit essential as initial capital for investing in tree planting (Ahman et al. 2012). Therefore, policy support to provide secure land titles to local people will be essential to enable pongamia adoption.

Development of the Government of Indonesia’s policy on biofuel-based energy is carried out using a SWOT analysis approach to analyse existing conditions, formulate problem-solving strategies, and develop policies for sustainable biofuel (Bappenas 2015). The General National Energy Plan (RUEN) has a number of long- and short-term programmes to support the National Energy Policy (Government Regulation No. 79/2014). RUEN targets to produce 15.6 and 54.2 million kilolitres of biofuel by 2025 and 2050, respectively (Traction Energy Asia 2020). To support government policy, sustainable energy plantations of adaptive and productive species could play a crucial role, especially when implemented on ex-mining and degraded land. Besides growing biofuel, such species can also fertilize soils and provide other benefits, e.g., income generation, improved biodiversity, and provision of multiple ecosystem services (Maimunah et al. 2018; Rahman et al. 2019).

Considering the diversity of biofuel production (and system components) across locations, there may be a shortage of specific evidence about variation in contributions to the delivery of various ecosystem services. Improving this knowledge base (e.g., through modelling) can be facilitated by research that produces a more sophisticated approach to incorporate the economic, social and environmental characteristics of biofuel.

Further, through strengthening and socializing biofuels as a strategic industry, increasing productivity and diversification of biofuel-producing plants, providing incentives for investment in biofuel facilities, encouraging market links, and increasing research budgets for the development of biofuel commodities and products can strengthen sustainable biofuel production.

13.5 Conclusions

Pongamia trees are well suited to growing in adverse environmental conditions. The species can grow in most soil types, in partial shade or full sunlight, and at various temperatures. Pongamia is a multipurpose tree that fixes atmospheric nitrogen, improves soil health and can produce large amounts of oil for biodiesel. It can produce bioenergy on degraded land unsuitable for food production. As Indonesia's large areas of degraded land deliver limited benefits to people and nature, restoring such land through pongamia cultivation could provide an opportunity to enhance ecosystem services and reverse biodiversity loss. Although several other species produce biofuel (e.g., oil palm, coconut or jatropha), with its multiple benefits (see Table 6), pongamia is a prime candidate for planting as a bioenergy feedstock on degraded land.

The Government of Indonesia's initiation of a national policy on new and renewable energy use, which includes biofuel making up 5% of the energy mix by 2025 (Kharina 2016), has significantly increased the importance of domestic biofuel production (Rahman et al. 2019). As palm oil production is widely questioned, pongamia could be a potential new alternative for cultivation on degraded land. However, it will necessitate long-term monitoring to prevent forest being cleared for biodiesel crop production (Rahman et al. 2019).

It was apparent from our literature review that scientific knowledge gaps remain, i.e., up-to-date pongamia production technology, long-term plantation management, community involvement, various added-value options (e.g., understory crop association), identifying potential biofuel producers and consumers, developing effective business models for various biofuel stakeholders, and the feasibility of building stable biofuel markets. Therefore, new studies on pongamia focusing on these issues could help to fill knowledge gaps and benefit scientific communities, managers and other stakeholders.

Appendix A

Table A1. Performance and management of pongamia in four different locations in Indonesia.

	Location			
Site Information	**Buntoi, Central Kalimantan**	**Kalampangan, Central Kalimantan**	**Wonogiri, Central Java**	**Parung Panjang, West Java**
Altitude (m)	18	12	142	52
Average annual rainfall (mm)	2992	2992	1878	2440
Average temperature (°C)	27.3	27.3	29.0	28.0
Soil type	Peat	Peat	Mineral (alfisol and entisol)	Mineral
Planting date	January 2020	January 2020	January 2020	February 2012
Spacing (m)	8 x 8	6 x 6	5 x 2	3 x 3
Stand density (per ha)	156	278	1000	1111
Planting system	Mixed with *nyamplung* (*Calophyllum inophyllum*)	Monoculture	Monoculture	Agroforestry with understory crops, i.e., pineapple (*Ananas comosus*), Asian blue ginger (*Alpinia galangal*), Cassava (*Manihot esculenta*)
Tree height (m)	1.26 (1 year old)	1.01 (1 year old)	1.49 (1 year old)	6.62 (8 years old)
Seed yield	N/A	N/A	N/A	3.80 kg per tree (i.e., 4222 kg per ha)

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CHAPTER 14

Ensuring monetary, human capital and natural capital returns in biomass production

Lessons from the Mentawai biomass gasification power plant project

Jaya Wahono, Michael Brady and Himlal Baral

Abstract: Primary energy demand in Indonesia is growing rapidly due to urbanization, economic development and population growth. The Government of Indonesia has mandated that new and renewable energy should contribute 23% of the national energy mix by 2025. Indonesia's updated Nationally Determined Contribution (NDC) stresses five sectors in which greenhouse gas (GHG) emissions are to be reduced, with land use, land use change and forestry (LULUCF) and energy being the highest priorities. While Indonesia is committed to addressing climate change through the LULUCF sector, there are clear contextual challenges that must be confronted to create the enabling conditions for REDD+, the main mechanism for carbon revenues, to contribute to landscape restoration in Indonesia. This chapter argues that biomass production for power plants in remote and isolated areas could become an additional agent of change in tackling this difficult problem. Using a case study from the Mentawai islands in Indonesia, we describe a methodology for rural electrification using a community- and biomass-based power generation system. The Mentawai model not only shows that biomass power plants can be used as the backbone for electricity generation in remote and isolated settings, but it can also be valuable tools to help alleviate poverty in underdeveloped regions in Indonesia as well as help finance the restoration of degraded and marginal lands. Replicating this system—one which results in biomass production, land restoration, affordable electricity and local economic growth—could improve the contribution of renewable energy to the energy mix and to the overall prosperity of Indonesians in rural and remote areas.

Keywords: rural electrification, biomass power plant, community based biomass production, ecosystem restoration, economic empowerment

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14.1 Introduction

Promoting renewable energy in Indonesia requires extraordinary effort because many of the islands across the entire country do not have reliable grids. This condition makes island grids mostly dependent on diesel-powered generators that provide power on demand amongst islands. Based on the National Electrification Ratio, Indonesia has successfully connected 97.5% of households to the electricity grid (ESDM 2019). However, efforts to achieve universal electricity access continue to prove difficult, especially for people living in small islands, those far inside dense forests, or those isolated from major human settlements (BPS 2013).

One of the main limitations of diesel-powered generators in remote areas is the costly operational expenses involved. Delayed fuel shipments due to bad infrastructure and unpredictable weather can cause these generators to run out of fuel (ESDM 2017). Yet increasing the use of renewable energy in such areas can be similarly challenging; applying solar and wind energy is difficult, for instance, due to their intermittency (Pérez-Arriaga and Batlle 2010; Ren et al. 2017). Additional high-cost infrastructure, such as batteries, liquid energy storage, and other forms of storage, are necessary to close the gap. Thus, the investment cost of renewable energy could be considerably higher than the renewable energy investment in other countries where higher capacity in one site is much more common. Indonesia's state-owned electricity company (PT PLN) has considered using a hybrid scheme with diesel power plants, in which renewable energy-based power plants act as the main power source, and diesel plants maintain base power supply and overcome the intermittent behaviour of renewable energy (Brahim 2019). However, this scheme is difficult to implement as diesel power plants still require reliable fuel supplies from other islands.

On the other hand, some renewable energy resources promise characteristics of continuous and stable electricity supply owing to their perpetual sources of energy (Shin et al. 2019). Hydro, geothermal and biomass are among such sources of renewable energy in Indonesia (IRENA 2017). Continuous load renewable energy is crucial in the development of archipelagic regions due to their capability to supply base load independently without additional hybrid connection using fossil energy. However, some renewable energy sources have obstacles related to development in small islands.

Hydropower derives from the energy that is produced when water moves from higher to lower elevations (Didik et al. 2016; Erinofiardi et al. 2016). This requirement is inconvenient on many islands as rivers are short and water levels fluctuate between seasons. Furthermore, some rivers are located remotely from the center of demand, which causes significant energy loss when energy is transferred to these areas. A similar challenge occurs with geothermal power (WWF 2012; Semedi et al. 2018; Ibrohim et al. 2019), where not every island has geothermal resources beneath the Earth's crust, particularly in Indonesia where most geothermal sources are located in the mountains. Long transmission is crucial, yet simultaneously inefficient due to energy loss. Additionally, geothermal power plants are often unsuitable for small islands. This is because the high investment cost necessitates a high capacity, which makes it inefficient to use the power only for small-scale mini grids.

Local biomass, on the other hand, can be utilized to create small-scale power plants that can be placed near centres of demand on small islands in Indonesia. Biomass resources consist of many different materials, including residual forestry waste, planted woody and non-woody biomass, animal residue, sewage and municipal solid waste (Liu et al. 2019; Perea-Moreno et al. 2019). Due to its conducive climate and soils, Indonesia has huge potential as a biomass producer, including its small island regions. Biomass can be produced locally and in the vicinity of a power plant, making such plants manageable in almost every area near a center of electricity demand (Shin et al. 2019).

This chapter describes a system of using small-scale biomass gasification as a solution for small-scale power plants in small islands in Indonesia.[1] As opposed to direct combustion of biomass combined with steam turbines, small-scale gasification processes are technically mature and behave similarly to diesel-powered generators. Gasification technology has lower emissions of NOx and SOx, more efficient heat, and fewer requirements for consumables. It is widely reported that gasification is appropriate for small-scale capacities from 10 kWe up to 1 MWe. Therefore, small-scale biomass gasification is preferable for the electrification of small islands because of its capacity to utilize local biomass resources and its ability to provide reasonable cost electricity, as no energy storage is required for such systems (Sonal 2009).

In the system, biomass is purchased directly from local communities, thus supporting local economic growth. Moreover, the system would support land restoration efforts, as to a significant extent, biomass planting areas would be selected to maintain land stability, restore degraded land and sequester CO_2. This chapter also identifies the use of REDD+ payments to enhance funds needed for land restoration with bamboo or other perennial plants, which could be used to produce feedstock for small-scale biomass gasification power plants.

This chapter highlights the proof of concept of the system developed in Mentawai Islands District in West Sumatra, Indonesia. At only 29.8%, the electrification ratio in the Mentawai islands is significantly lower than the national average of 97%. The district has power plants in three isolated villages: Madobag (300 kW), Matotonan (150 kW) and Saliguma (250 kW). These power plants run on local forest biomass, particularly bamboo. Owing to its capability to reinforce degraded land and intercropping behaviour, and its high calorific value, bamboo is planted on a large scale in the Mentawai islands in villager-managed social forestry schemes. This strategy in the Mentawai region serves as a proven model

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[1] Gasification is a process in which solid biomass is converted into combustible gases.

for replication of small-scale biomass gasification power plants on other islands with low electrification ratios.

The contributions of this chapter, therefore, are as follows:

- A methodology is provided for renewable energy-based rural electrification in Indonesia, which covers the social, economic and political aspects of electrification.
- A business model is highlighted, whereby rural electrification and employment creation are carried out simultaneously, promoting sustainable development of rural areas. The business model further shows that community biomass-based power plants could receive enhanced funding through carbon credit schemes.

The rest of the chapter is organized as follows: Section 2 elaborates on the problem description and the methodology applied. Section 3 reviews socioeconomic conditions in the Mentawai Islands prior to the biomass gasification project. Section 4 focuses on biomass gasification project implementation in the Mentawai islands, and is followed by a conclusion in Section 5.

14.2 Original problem description and methodology applied

14.2.1 Original problem description in the Mentawai islands

By surveying the needs of locals in the Mentawai islands, we identified several problems in bringing reliable electricity to communities. By holding public consultations with various stakeholders in the island district, we then formulated a solution that satisfied the following conditions:

(C.1) The energy source is renewable and can be obtained locally;
(C.2) The harvesting process of the energy source has a minimal impact on the ecological system, and must involve reforestation efforts;
(C.3) The generation system must be dispatchable and scalable;
(C.4) The electricity produced must be equitable, reliable and affordable.

The first point in condition (C.1) was mandatory to support the Government of Indonesia’s plan for renewable energy to contribute 23% of the national energy mix by 2025. The second point under (C.1) was intended to tackle two things: (1) to minimize raw material costs, and (2) to create local employment, which in turn would boost the local economy. These could be achieved with the intended solution, as it would result in lower electricity generation costs, thus making electricity more affordable, while simultaneously fostering local employment in support of sustainable development. Overall, this meant that communities could afford to purchase the electricity since they would have an earnings source (due to increased employment), and the electrification would be sustained since people would purchase the power generated.

The specificity of (C.2) strengthened the first point under condition (C.1) by clarifying what renewable energy sources were most appropriate for sustainable development. Suppose the energy source was renewable, but harmed the ecological system in other ways: for instance, solar-based power which required deforestation for the installation of solar panels, then deforestation would increase the reflectivity of the land surface and evapotranspiration, and would also cause consistent warming, meaning the ecological benefits of using the renewable energy source would be negated, at least partially. Reforestation efforts were aligned with the Government of Indonesia's NDC and, in addition, would enable REDD+ conditions which could only be paid as a result of reducing deforestation and land degradation.

The first point under condition (C.3), dispatchability, was mandatory for power generation. Meanwhile, the second point under (C.3), scalability of power generation, was required since the electrification was meant for rural areas where the population is distributed unevenly due to geographical conditions, but electrification could also drive industrial growth in those areas, which could possibly create greater energy demand in the future.

Condition (C.4) regarding equitability, reliability and affordability was primarily affected by the business and political circumstances surrounding power generation. Electrification in rural areas greatly depends on funding, and the management of funds involves the central government, local government and the private sector. Equitability meant that the electricity produced must benefit all community members living in the respective villages. This way, all village people would support the electrification programme and consequently it would be more sustainable, both financially and economically. Reliability meant that the electricity produced must be resilient to any changes in economic, social or political circumstances. Lastly, affordability meant that rural communities would be able to purchase electricity without having to sacrifice their primary needs.

Conditions (C.1) to (C.4) ensured the workability and sustainability of the rural electrification. REDD+ conditions alone were not sufficient to make the whole development workable and sustainable; indeed, there were economic, social and political aspects that also had to be considered. Economically, REDD+ actions are expected to increase carbon stock in addition to other major functions in forestry (Ricard et al. 2011). Carbon emissions reductions are supposed to be credited and incentivized through community-based schemes. Socially, harmonization with other relevant sectors, such as agriculture, water resources and energy, was also important to reduce potential future conflict. Conciliation with small and medium communities, such as schools, hospitals and wood consuming companies, is also crucial to promote REDD+ actions. Politically, it was important to link with national renewal energy initiatives and strategies in regional and national policies, as institutional frameworks or environmental programmes are also essential for implementing REDD+ actions (Ricard et al. 2011).

14.2.2 Methodologies applied

Methodologies were formulated so results achieved in Mentawai Islands District could be replicated in other rural areas. The formulation consists of seven methodologies:

(M.1) Determine the rural area to be electrified

A rural area prioritized for electrification should be an area with a low electrification ratio. It should also be an area the government intends to electrify. Such areas are commonly referred to as 3T (*Terdepan, Terpencil dan Tertinggal*) areas, meaning frontline, isolated underdeveloped areas. If the chosen area aligns with government plans, then relatively speaking, political barriers should be fewer. According to Indonesia's Ministry of National Development Planning (Bappenas 2019), there are 52 3T areas in Indonesia that require electrification with a capacities of 5 to 10 MW.

(M.2) Selection of renewable energy source

The renewable energy source must be selected to comply with conditions (C.1), (C.2) and (C3). Therefore, the only suitable renewable energy source that can be obtained through reforestation is biomass, such as bamboo (Darabant et al. 2014; Sharma et al. 2018; Yoesgiantoro et al. 2019). Solar energy can meet criteria (C1) and (C2), but not (C3), as solar PV plants can only generate power when the sun is shining. Battery storage can be added, but this solution would have a minimal social and economic impact in providing employment in local communities, which would ultimately have to rely on government subsidies. In contrast, by sourcing feedstock from surrounding communities, biomass power plants can increase local capacity to afford electricity.

(M.3) Establishment of a business model

A business model must be established before any engagement with other stakeholders. In addition, the business model must facilitate the following:

- local employment creation, which will focus on employing rural women and youth;
- equitable electricity generation, in which the biomass will be sourced exclusively from local biomass producers;
- sustainable electrification, which will be guaranteed by PLN as sole off taker of electricity produced by biomass power plants.

Figure 1 shows the intended business model where Indonesia's Environment Fund Management Agency or *Badan Pengelola Dana Lingkungan Hidup* (BPDLH) interacts with the local community, the independent power producer (IPP) and state-owned electricity company *Perusahaan Listrik Negara* (PLN). A Power Purchasing Agreement (PPA) with

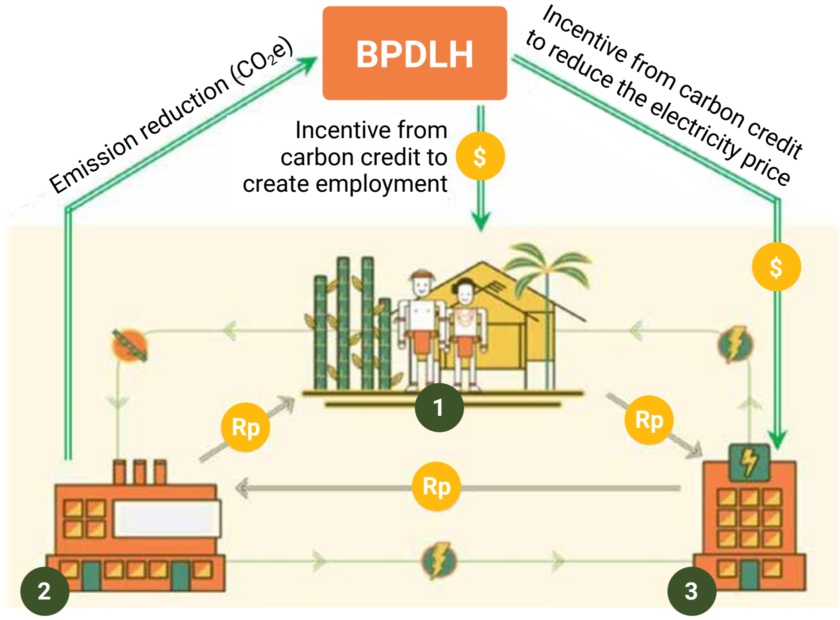

Figure 1. The proposed business model for rural electrification in Indonesia: (1) represents the local community; (2) represents the IPP; and (3) represents state-owned electricity company, PLN

PLN for a duration of 20–25 years is the one single factor making a biomass power plant project bankable in the eyes of investors and lenders. Once a project is bankable, it can easily be put out for tender. An open and high-quality tender process will then ensure the budget and schedule for completion of the project can be predicted with relative accuracy.

The other important party in the scheme is BPDLH, a newly formed non-structural entity under the Ministry of Finance created to manage funds for environmental protection and management, including climate change mitigation and adaptation efforts. The regulatory framework for BPDLH provides a solid legal basis for a robust and flexible vehicle to fund activities in the public interest, including managing money from international donors. Under the scheme, a local community would plant biomass and sell it to an IPP, which would then generate electricity for sale to PLN, which, in turn would sell the electricity to the local community. Since the electrification process would involve reforestation, such a system may be entitled to REDD+ incentives managed by BPDLH. Accordingly, this chapter suggests that carbon credit payments be used to enhance employment opportunities and reducing electricity prices in the long term.

To the best of the authors' knowledge, the business model in Figure 1 is the first model that connects preservation of the environment with employment creation and rural electrification. Even without carbon credit payments, the interaction between (1), (2) and (3) in Figure 1 would guarantee sustainable electrification. However, the addition of carbon credit payments would facilitate faster development in rural areas, and would also provide sustainable electrification as a result of the low prices paid for electricity. Ultimately, carbon credits could be used to cover the capital expenditure for initiating the development of a rural electrification project.

(M.4) Secure an MoU with the local branch of PLN

In Indonesia, PLN is the official entity that can sell electricity to the public. Therefore, PLN must be involved in any rural electrification plan for a rural area. The local PLN must be convinced to purchase the electricity produced by the IPP so that the business model in Figure 1 can be implemented.

(M.5) Feasibility study

A feasibility study must be carried out to predict the economic value of electrification. The result from this study could be used as justification for the electrification plan at both social and political levels.

(M.6) Securing funds for development

One of the reasons that Indonesia still has many areas with a low electrification ratio is the lack of funding. By conforming to conditions (C.1) to (C.4), a rural electrification plan would be entitled to financing from the Environment Fund managed by BPDLH (Setkab 2019). BPDLH is the national agency that manages funds relating to forestry, energy and mineral resources, carbon trading, environmental services, industry, transportation, agriculture, marine and fisheries and other fields related to the environment. The sources of funds managed by BPDLH can be categorized as follows:

- Carbon/emissions trading
- Soft loans, senior loans and subordinated debts
- Conventional grants
- Subsidies for environment-related issues
- Government Viability Gap Funding (VGF) support
- Equity

(M.7) Detailed planning for electrification

Last but not least is the detailing of a technical plan for electrification in consultation with all relevant stakeholders. This step, which can be carried out once steps (M.1) to (M.6) have been finalized, is not discussed in this chapter.

14.3 Demographic, socioeconomic and geographic conditions in Mentawai Islands District

This section describes the unique situation that most remote communities in Indonesia face in terms of electricity access, resulting in the necessity to find radically different solutions for electrification—in other words, to find solutions other than the conventional electricity access widely available in major islands like Java and Sumatra.

14.3.1 Summary of geographical conditions

Mentawai Islands District is located in West Sumatra Province at a latitude of 0°55’00” – 3°21’00” S and longitude of 98°35’00” – 100°32’00” E. The district covers an area of approximately 6,011.35 km^2 and has 1,402.66 km of coastline. Geographically, Mentawai Islands District is separated from the West Sumatra mainland to the east by the Mentawai Strait. The district borders the Siberut Strait to the north, and the Indian Ocean to the south and west. In summary, Mentawai Islands District is an isolated region along Indonesia’s western border.

The district comprises 99 islands, with Siberut being much larger than all others. Geographically and administratively, Mentawai Islands is made up of 10 subdistricts, 43 definitive village regions and 341 hamlets. The district has a varied topography, with coastal plains, rivers and hilly terrain. The average elevation of all the district’s administrative capitals is two metres above sea level. The district capital, Tuapeijat, is located in North Sipora Subdistrict.

Based on Central Statistics Agency data (BPS 2018), Mentawai Islands District has 456,301 ha of forest cover making up 76% of the total district area. Only 3,096 ha or 0.5% of the district area comprises settlements. The average distance from Tuapeijat to Mentawai Islands’s subdistrict capitals is 94 km, with boats or speedboats being the main means of transport for the local populace.

14.3.2 Population in Mentawai

The district’s population in 2018 was 90,373, comprising 46,998 men and 43,375 women. Within the population, 12,990 people were categorized as poor due to having household incomes of less than USD 2 a day. The district has a Human Development Index (HDI) of 60.28, which is below the HDI of 71.73 for West Sumatra Province as a whole. Average population density in Mentawai Islands District in 2018 was 15 people per km^2. Sikakap Subdistrict had the highest population density at nearly 37 people per km^2, while West Siberut Subdistrict had the lowest at only 7 people per km^2. The total population aged 15 years and over in Mentawai Islands District was 57,790. Economic activities of the population are shown in Table 1.

Using data from Table 1, unemployment rates, calculated by the ratio of

$$\left(\frac{\textit{unemployed}}{\textit{economically active}}\right) \times 100\%,$$

were 1.55% for men and 3.26% for women. Meanwhile, economic participation rates, calculated at,

$$\left(\frac{\textit{economically active}}{\textit{total population}}\right) \times 100\%$$

were 82.3% for men and 55.31% for women.

Education levels of economically active residents are shown in Table 2.

Table 2 shows that in 2018, almost half of the economically active population either had no educational background or only finished primary school.

Table 1. Population aged 15 and over by type of activity

Main activity	Men	Women	Total
Economically active	25,008	18,172	43,180
Working	24,621	17,579	42,200
Unemployed	387	593	980
Economically inactive	5,379	9,231	14,610
Attending school	3,075	3,085	6,160
Housekeeping	751	6,031	6,782
Other	1,553	115	1,668
Total	30,387	27,403	57,790

Source: BPS 2018

Table 2. Economically active population aged 15 or older by level of education

Education	Working	Unemployed	Total
No education or did not complete primary school	14,125	-	14,125
Primary school	12,741	119	12,860
Junior high school	5,773	79	5,852
Senior high school	6,793	782	7,575
Diploma I/II/III	813	-	813
University	1,955	-	1,955
Total	42,200	980	43,180

Source: BPS 2018

14.3.3 Electrification in Mentawai Islands District

At only 29.8%, the electrification ratio of Mentawai Islands District is significantly lower than the average for West Sumatra Province at 86.6% (Yoesgiantoro 2019). Most areas in the Mentawai islands use diesel-powered plants operated by PLN, which are not capable of operating for 24 hours a day. Data to December 2013 from the Mentawai Archipelago PLN division states that it had 5,524 customers across the archipelago's ten subdistricts. This was an increase from 2012, and PLN projected increasing numbers of customers in years to come.

In 2013, the subdistrict with the most PLN customers was North Sipora with 2,223, or 40.24% of all customers across the archipelago, most of them living in Tuapeijat. This was followed by South Siberut Subdistrict with 966 customers (17.49%), predominantly in Maileppet Village, and South Sipora Subdistrict with 862 customers (15.60%), mainly in the Sioban Village region.

Numbers of PLN customers above cover social, household, business and government users. The largest percentage of users, at 4,849 customers or 85.69%, was households, while the public sector accounted for the smallest percentage of users at 2.43%, or 134 customers.

14.3.4 Remarks on socioeconomic conditions in Mentawai Islands District

Due to the circumstances described above, Mentawai Islands District is considered a top priority region for electrification. As one of Indonesia's '3T' areas, its electrification ratio is still very low, and most of the district's power plants run on diesel and are incapable of providing electricity for 24 hours a day. Adding more power plants in the district would increase its electrification ratio. Overall, the potential exists to replace its diesel power plants with GHG emission reducing, renewable energy-based power plants.

The data from Table 1 shows the Mentawai people are economically active. They are also familiar with the local biomass (bamboo). Since rural areas in the Mentawai islands are an average 5-hour express boat ride away from the district's main towns, power plants needed to be developed in rural areas and had to be self-sufficient, meaning the fuel source must be obtained locally. This is also the reason why establishing diesel power plants across Mentawai Islands District would be prohibitively expensive. Consequently, a distributed power generation system using local sources of energy provided a better option. Implementing the business model in Figure 1 provided a dual incentive for Mentawai people with more employment opportunities and increased access to electricity. The business plan has contributed positively to the local economy and the wellbeing of the Mentawai people, while also promoting renewable energy projects.

14.4 Biomass gasification for power generation in Mentawai Islands District

The biomass gasification project in the Mentawai islands is being implemented by Clean Power Indonesia (CPI). Initial funding for the project came in the form of a Millennium Challenge Account (MCA) grant. Total funding for the project was USD 13.4 million (including detailed feasibility study), where 96% was covered by the MCA grant. CPI applied for and secured the MCA grant, and took on the role of independent power provider (IPP). Detailed technical planning (engineering, construction and procurement) was carried out by the contractor.

The main purpose of the project was to introduce and develop renewable energy power plants in rural areas inaccessible to PLN. Prior to project implementation, CPI approached the local PLN division to convince officials of the project's merits and the benefits for all stakeholders involved. This step (M.4), discussed in Section 2 above, was to emphasize that the power plant being developed by CPI would be owned by the Government of Indonesia, and eventually the local community, and that CPI's role would merely be as a developer and enabler. Further, the electricity produced from the biomass gasification would be sold to the public and managed by PLN.

Bamboo was chosen as the biomass source for the project. The choice of bamboo as the renewable energy source aligned with conditions (C.1) and (C.2) because it would have a minimal impact on existing ecosystems and result in reforestation. The following were the most important reasons behind the choice to use bamboo as the biomass source in the project:

- Bamboo is socially acceptable in the Mentawai islands, as local people have nurtured a deep familiarity with bamboo for generations.
- Bamboo has a small ecological footprint, as it is planted on marginal land.
- Bamboo is supported by a legal framework for community-based plantations from the Ministry of Environment and Forestry of Indonesia, which recognizes bamboo as being suitable for restoration (MoEF 2018).
- Bamboo is suitable as fuel in biomass power plants (Engler et al. 2012).

An illustration of project implementation in the Mentawai Islands is presented in Figure 2. The fuel for the power plants is synthesis gas from a bamboo gasification process. This process also produces ash, and charcoal that can be used as cooking fuel. In addition, gas exhausts from the bamboo biomass-based power plants can be used for crop drying. Consequently, using bamboo is the optimum and most sustainable choice for supporting the economic activities of the rural population, as many of its by-products have other uses.

Locations for the gasification project, which commenced in 2018, are the villages of Madobag, Matotonan and Saliguma on Siberut island. Madobag and Saliguma villages can only be reached by boat from the main town on Siberut in three and five hours, respectively.

Meanwhile, Matotonan Village can only be reached by walking for eight hours or by boat in around six hours. The total power generation capacity of plants in the three villages is 700 kW, which covers 1,181 households and 456 non-residential connections. Figure 3 shows the first time the lights were illuminated at the power plant in Saliguma Village, the first bamboo-based biomass power plant in the Asia Pacific region.

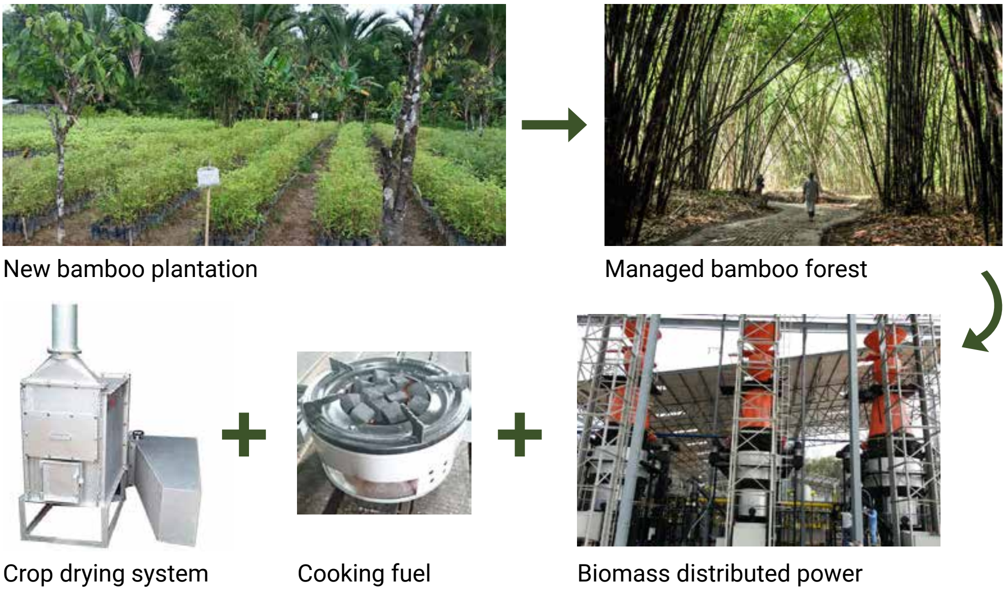

Figure 2. Illustration of project implementation in Mentawai Islands District

Figure 3. Documentation by CPI: The inaugural light up of the bamboo-fired power plant in Saliguma Village

Communities provide the bamboo as biomass for the power plants (Figure 1 in Section 2). Each household received 100 bamboo seedlings, where: (i) one seedling would provide 100 poles within five years, with (ii) one pole weighing 20 to 30 kg. Consequently, one household needs only two or three poles per month to meet its own energy needs. Community roles in supplying bamboo are illustrated in Figure 4 below. Figure 4 (a) shows villagers collecting and transporting bamboo poles from their plantation. Figure 4 (b) shows villagers drying cut bamboo poles, which must be dried for three days, and preparing them for collection by the IPP. Figure 4 (c) shows a representative from the IPP collecting dried cut bamboo poles for further processing at the power plant. In implementing these processes, villages apply consensus-based decision-making to establish how much bamboo each household needs to supply to avoid over-supply to the IPP.

Data from the Directorate General of New-Renewable Energy and Energy Conservation shows the monetary value of employment opportunities created by the gasification project in the Mentawai islands to be roughly IDR 2 billion per year. This figure includes contributions to communities for supplying bamboo to the IPP, and remuneration from jobs with the IPP, which are open to applicants from local communities. Meanwhile, according to the Alliance for Rural Electrification (ARE 2019), the biomass gasification project has created around 450 jobs. This employment creation is an important feature of the business model in Figure 1.

Features of the biomass gasification project in Mentawai Islands District are as follows:

1. Land concessions: The local government has given local communities the right to use land to plant bamboo, which ensures supplies of biomass for the power plants. In return, these land concessions have resulted in reforestation.
2. Accessibility: The electricity generated by the biomass power plants on Siberut island is managed by the local PLN. Thus, guaranteeing its accessibility to local communities.
3. Affordability: Local communities are remunerated for supplying the raw energy source to the IPP, and have additional income that can be used for purchasing electricity managed by the local PLN. Consequently, local communities are able to afford electricity.
4. Acceptability: Planting bamboo is socially acceptable for the people of the Mentawai islands. The local government also supports bamboo planting because it has always been done on marginal or unproductive land. From an outsider’s perspective, the planting of bamboo is widely acceptable as it reduces GHG emissions.
5. Sustainability: The business model is sustainable due to the guaranteed supply of biomass within a 5 km-radius of the power plants. Additionally, the IPP’s business is sustainable due to guaranteed electricity purchases from the local PLN. Finally, the local PLN can maintain a sustainable customer base and can benefit from the Environment Fund managed by BPDLH to reduce electricity prices.

a

b

c

Figure 4. Documentation by CPI: People in Mentawai: (a) collecting and transporting bamboo poles; (b) drying cut bamboo poles and preparing them for collection by IPP; and (c) IPP representative collecting dried cut bamboo poles

14.5 Conclusion

The gasification project in Mentawai Islands District discussed in this chapter conforms to four key conditions namely, (i) energy sources should be sourced locally (ii) the harvesting, process of the energy sources has a minimal impact on the ecological system and must involve reforestation efforts, (iii) the generation system must be dispatchable and (iv) the electricity produced must be equitable, reliable and affordable. and scalable. In addition, the project in Mentawai has shown that methodologies (M.1) to (M.6) described in this chapter can successfully realize the electrification of rural areas in Indonesia by using renewable energy.

Funding for the gasification project in Mentawai Islands District came from a Millennium Challenge Account (MCA) grant. Although this grant is not available to other regions, the project in Mentawai Islands District has shown that similar projects in other areas may receive financing from the Environment Fund managed by BPDLH, which could be used for supporting development. Community- and nature-based solutions for biomass planting will help to secure feedstock in the long term and create feedstock supply security for biomass power plants. This is a solution to promote biomass power plant development all over the country, while simultaneously replacing expensive and polluting diesel generators.

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